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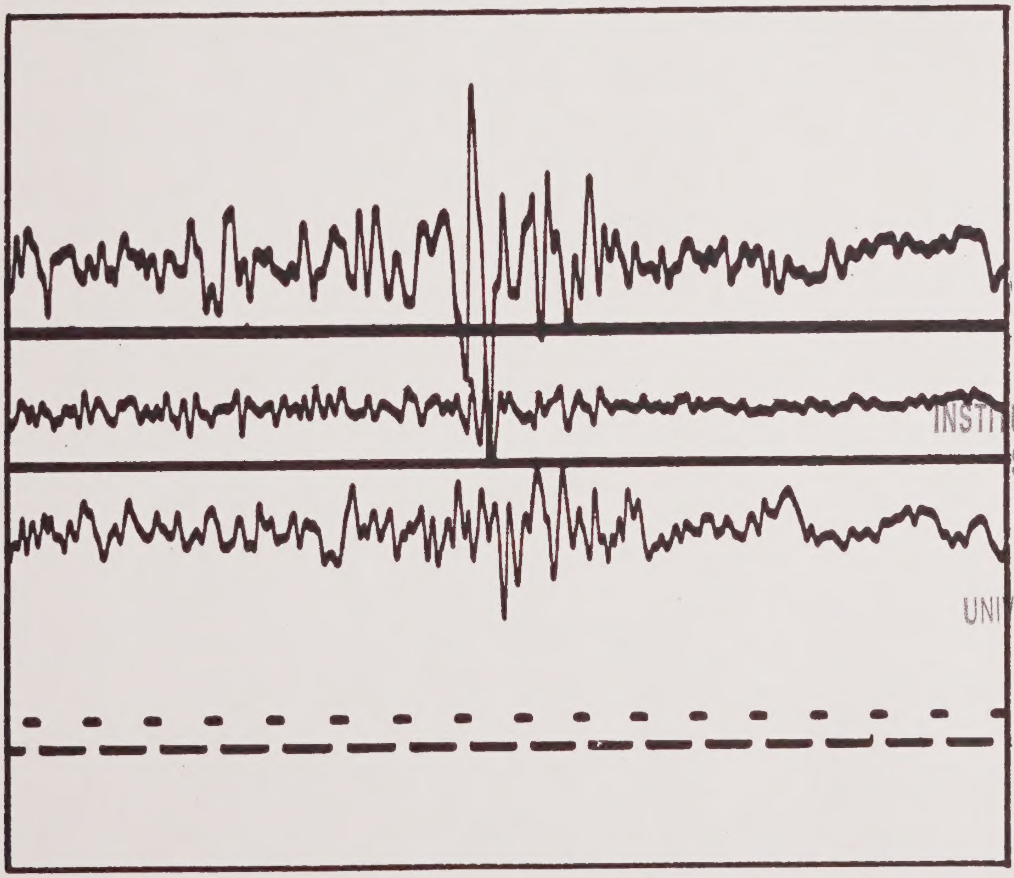
SAFETY ELEMENT OF THE GENERAL PLAN

TECHNICAL BACKGROUND REPORT



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CITY OF SANTA MONICA, CALIFORNIA

JANUARY, 1995

TECHNICAL BACKGROUND REPORT TO THE SAFETY ELEMENT OF THE CITY OF SANTA MONICA GENERAL PLAN

January, 1995

Project No. 2910399-01

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CHAPTER 1: SEISMIC HAZARDS

Earthquakes are a fact of life in southern California. Although it is not possible to prevent earthquakes from occurring, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can reduce significantly the scope of an earthquake disaster. It is with this purpose in mind that Government Code Section 65302(g) requires local governments to address seismic safety issues in their General Plan, detailing the goals, policies and programs that they have adopted as part of a hazard mitigation program.

Various geologic phenomena that can cause severe property damage and loss of life are triggered by earthquakes. These hazards include ground shaking, fault rupture, landslides, foundation failures caused by liquefaction or subsidence, tsunami and seiche. Santa Monica is susceptible to damage from any of these hazards. Earthquakes can also cause a variety of localized, but not less destructive hazards such as urban fires, dam failures, and toxic chemical releases.

This chapter concentrates on the seismic hazards of ground shaking, fault rupture and liquefaction as they pertain to both proposed development and existing facilities in the City of Santa Monica. Where necessary, each section on seismic hazards begins with an introduction where pertinent terminology is defined and where background information is presented. Following chapters discuss in detail the geologic hazards of landslides and subsidence (Chapter 3), and the hazards of dam failure and tsunami inundation (Chapter 4), urban fire (Chapter 5), and releases of hazardous substances (Chapter 6).

1.1 GROUND SHAKING HAZARD

Several faults have the potential of generating earthquakes that will cause strong ground motions in southern California, including in the City of Santa Monica. Each of these potential earthquakes will affect the City differently, depending on the distance between the earthquake-generating fault and Santa Monica, the size and rupture mechanism of the earthquake, and the local geologic conditions. Some faults are also more likely to cause an earthquake than others.

Seismic waves propagating through the earth's crust are responsible for the ground vibrations normally felt during an earthquake. Seismic waves vibrate up and down and side to side at different frequencies, depending on the frequency content of the earthquake rupture mechanism, the distance from the earthquake source to a particular site, and the path and material through which the waves are propagating. As seismic waves travel through the earth's crust, their energy is lost due to the inelastic behavior of the ground motion, and due to scattering, diffraction and deflection of the waves as they cross materials of different physical properties. The overall effect, known as attenuation, alters the form and frequency content of the seismic waves with distance away from the earthquake's source.

Near-field earthquakes, which occur within approximately 10 miles (about 10 miles) of the site of reference, generate rough, jerky, high-frequency seismic waves that are generally more efficient in causing short buildings, such as single-family residential structures, to vibrate. Longer period wave forms, characteristic of far-field earthquakes, are felt at greater distances from the earthquake source. These longer-period waves, manifested as a slow rolling motion, are more likely to cause high-rise buildings and buildings with large floor areas to vibrate vigorously. An earthquake on the San Andreas fault would be an example of a far-field earthquake in Santa Monica, as opposed to a near-field event on the Santa Monica fault.

Faults in the Los Angeles region have formed over millions of years as a response to various tectonic stress regimes. Some of these faults are generally considered inactive under the present geologic conditions, that is, they are unlikely to generate any future earthquakes. Other faults are known to be accumulating strain as a result of current shifting of the earth's plates. Such faults have either generated earthquakes in historical times, or show geologic and geomorphic characteristics that suggest that they might move in the relatively recent future, within a time span of concern to the residents of the area, or for long-term consideration in building design.

In general, the probability of an earthquake occurring on a given fault decreases with age of the latest proven faulting. However, it is at times difficult to determine with a certain degree of confidence, which faults are capable of moving in the future, and which ones are not likely to move under the present stress regime. Geologic evidence suggests that some faults may remain dormant for hundreds to thousands of years between major displacements. Different regulatory agencies have enacted fault classification systems, however, the geologic time scale (Table 1.1) is often used as a yardstick of latest proven faulting to evaluate the risk a fault may pose to development. The State of California uses the following classification scheme as part of the Alquist-Priolo Special Studies Zone (APSSZ) Act of 1972 (Hart, 1990):

- Active faults are those which have been proven to have moved within about the last 11,000 years (Holocene).
- Potentially active faults are those which show evidence of surface displacement within the last two million years (Pleistocene), but which have not been proven to displace or not displace sediments younger than 11,000 years (Holocene).
- Inactive faults are those which have been proven, by direct geologic evidence, not to have moved within the last 11,000 years (Holocene).

The APSSZ Act fault classification is geared toward the regulation of surface rupture hazards impacts for human occupied structures. Potentially active faults, however, need to be considered in the design phase and seismic analyses of many types of projects, such as fire stations, dams and emergency operation centers. When their risk cannot be established, potentially active faults may also be treated in the same manner as active faults, including designating building setbacks if necessary. The activity classification of faults may also change as geologic field studies along the trace of the fault are conducted, or if an earthquake occurs on a fault previously considered inactive. Some historical earthquakes have even occurred along previously unknown faults.

Table 1.1

Geologic Time Scale

PERIOD	EPOCH	AGE (Years)
Quaternary	Holocene	10,000
	Pleistocene	1.6 Million
Tertiary	Pliocene	5.3
	Miocene	23.7
	Oligocene	36.6
	Eocene	57.8
	Paleocene	66.4
Cretaceous		144
Jurassic		208
Triassic		245
Permian		286
Carboniferous		360
Devonian		408
Silurian		438
Ordovician		505
Cambrian		570
Pre-Cambrian		4.5 Billion (approx. age of the Earth)

Abbreviated version of the geologic time scale (Geological Society of America, 1983). The ages shown mark the beginning of each period or epoch, that is, for example, the Cretaceous is the geologic name for that period of time that occurred between about 144 and 66.4 million years ago. Surficial deposits in Santa Monica are of Holocene and Pleistocene age (younger than 1.6 million years). Under the Alquist-Priolo Special Studies Zones Act, active faults are faults that show evidence of having displaced deposits younger than about 11,000 years old, roughly equivalent to within the Holocene.

A maximum probable earthquake is the largest earthquake a fault is predicted capable of generating within a specified time period of concern, say 30 or 100 years. Maximum probable earthquakes are most likely to occur within the time span of most development, and therefore, are commonly used in assessing seismic risk. The maximum credible earthquake, i.e. the largest earthquake a fault is believed capable of generating, is nevertheless, often considered in a number of planning and engineering decisions. For example, maximum credible earthquakes are considered in the design of critical facilities such as dams, fire stations, and emergency operation centers. They are also used in urban and emergency planning to identify and mitigate the risk of worst-case scenarios.

Earthquakes are normally classified as to severity according to their magnitude (usually using the Richter scale), or their seismic intensity. Richter magnitude is a logarithmic measure of the maximum motions of the seismic waves as recorded by a seismograph. Because this size classification is based on a logarithmic scale, a magnitude 8 earthquake is not twice as big as a magnitude 4 earthquake, but rather, 10,000 times larger. The destructiveness of an earthquake at a particular location is commonly reported using a seismic intensity scale. Seismic intensities are subjective classifications based on observations of damage caused by past earthquakes. There are several seismic intensities; the one used most often is the Modified Mercalli (MM) Scale (Table 2.2). This scale has 12 levels of damage; the higher the number, the greater the damage. Earthquakes have only one magnitude, but they have variable intensities that generally decrease with increasing distance away from the source.

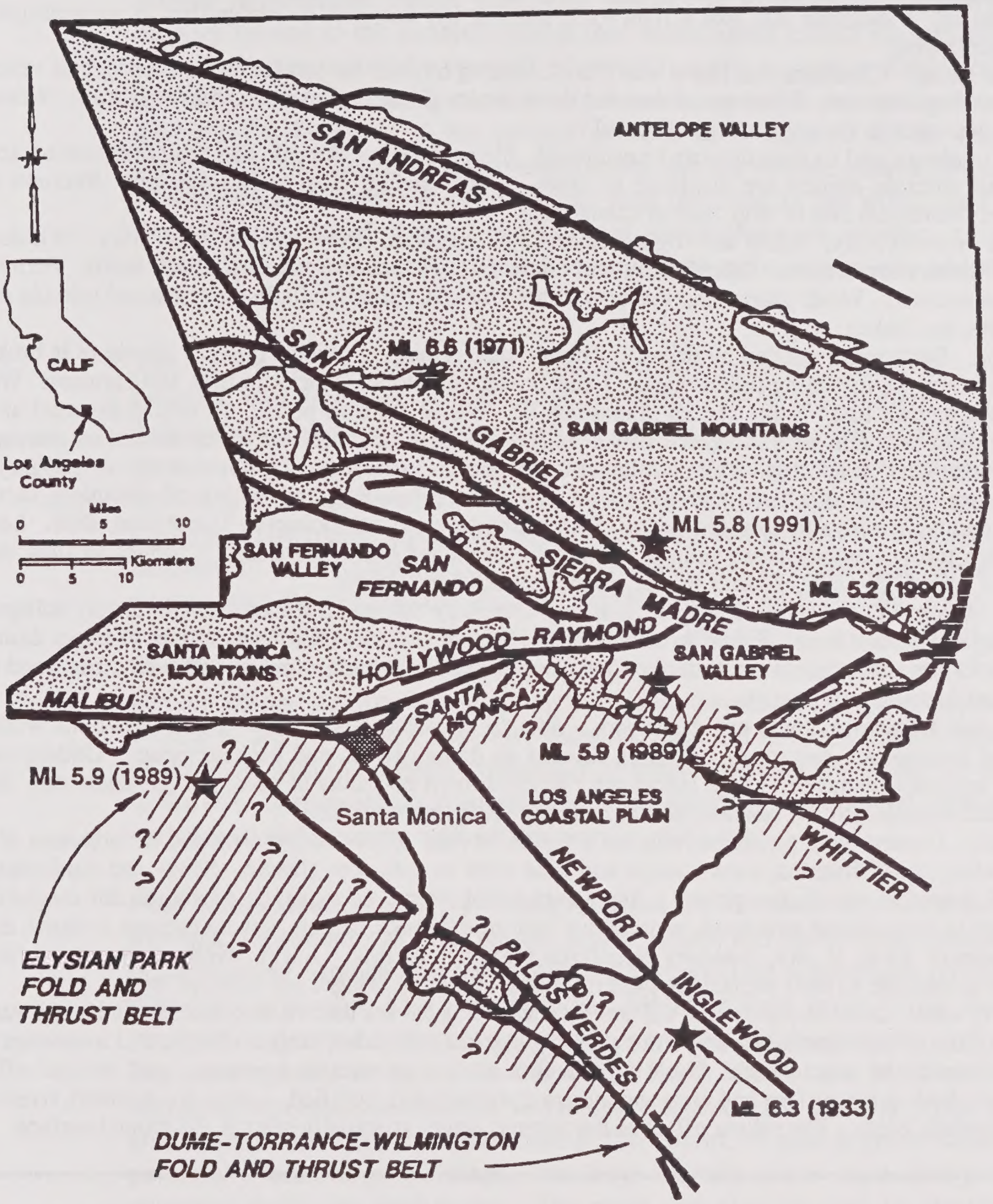
1.1.1 Hazard Analysis

While this document was being finalized, a magnitude M_w 6.7 earthquake occurred on January 17, 1994 with an epicenter located approximately 24 km (15 miles) north of Santa Monica in the Northridge/Reseda area. Substantial damage resulted from the earthquake, particularly in the northern portion of the City in the area of the east-west trending Santa Monica fault. As more information about the earthquake becomes available and further analysis is done, the City should evaluate the data and make determinations about amending or adding data to this section of the document.

Santa Monica is located near the south facing flank of the Santa Monica Mountains, in the northwestern most reaches of the Los Angeles Basin. This area of southern California is a transition zone between two tectonic regimes, the north to northwest trending strike slip system characterized by the Newport-Inglewood, Palos Verdes and Elsinore-Whittier-Chino fault systems, and an east-west trending system of thrust faults that includes the Malibu Coast-Santa Monica-Hollywood, the Sierra Madre and Cucamonga faults, and several "blind" or buried thrust faults (Figure 2.1). This system of thrust faults accommodates the compressional regime responsible for the formation of the Santa Monica and San Gabriel Mountains. Of all the earthquake sources presently known in southern California; the San Andreas fault, the Newport-Inglewood fault, the Santa Monica-Malibu Coast fault system, and possibly the Palos Verdes fault are particularly relevant to the City of Santa Monica.

Figure 1.1

Selected Faults and Historical Earthquakes in the County of Los Angeles


ANTELOPE VALLEY
SAN ANDREAS
CALIF
Los Angeles County
Miles
0 5 10
Kilometers
0 5 10
ML 6.6 (1971)
SAN GABRIEL
SAN GABRIEL MOUNTAINS
ML 5.8 (1991)
SAN FERNANDO VALLEY
SAN FERNANDO
SIERRA MADRE
ML 5.2 (1990)
SANTA MONICA MOUNTAINS
HOLLYWOOD–RAYMOND
SAN GABRIEL VALLEY
MALIBU
SANTA MONICA
ML 5.9 (1989)
ML 5.9 (1989)
Santa Monica
LOS ANGELES COASTAL PLAIN
WHITTIER
NEWPORT
INGLEWOOD
PALOS VERDES
ELYSIAN PARK FOLD AND THRUST BELT
ML 6.3 (1933)
DUME-TORRANCE-WILMINGTON FOLD AND THRUST BELT

Map of the Los Angeles County showing the approximate location of the City of Santa Monica in relation to selected faults and a few historical earthquakes. The shaded areas show the hilly and mountainous portions of the County. Note the approximate location of the Elysian Park and Dume-Torrance-Wilmington fold and thrust belts. (Figure modified from Sanchez et al., 1991).

Table 1.2

MODIFIED MERCALLI INTENSITY SCALE*

I Tremor not felt.

II Tremor felt by persons at rest or in upper floors of a building.

III Tremor felt indoors. Vibrations feel like a light truck passing by; may not be recognized as an earthquake. Hanging objects swing.

IV Hanging objects swing. Vibrations feel like a heavy truck passing by, and the jolt feels like a heavy ball striking the walls. Standing cars rock. Windows, dishes and doors rattle. Glasses clink and crockery clashes. Wooden walls and frames crack in the upper range of scale IV.

V Earthquake felt outdoors, and its direction can be estimated. Sleepers are awakened. Liquids are disturbed, some spilled. Small unstable objects are displaced or upset. Doors swing, closing and opening. Shutters and pictures move. Pendulum clocks stop, start or change rate.

VI Earthquake felt by everybody. Many are frightened and run outdoors. Persons walk unsteadily. Windows, dishes and glassware are broken. Knickknacks and books fall off shelves; pictures fall off walls. Furniture moves or is overturned. Weak plaster and masonry D are cracked. Small bells in churches and schools ring. Trees and bushes are shaken.

VII Difficult to stand. Earthquake noticed by drivers of motor cars. Hanging objects quiver. Furniture is broken. Damage to masonry D, including fallen plaster, loose bricks and stones, cracks in tiles and cornices. Weak chimneys break at roof line. Some cracks in masonry C. Waves form in ponds, disturbing the mud at the bottom. Slides and caving in sand and gravel banks. Large bells ring. Concrete irrigation ditches are damaged.

VIII Steering of motor cars is affected. Partial collapse of masonry C structures. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting and falling of chimneys, factory stacks, monuments, towers and elevated tanks. Frame structures, if not bolted to foundation, shift. Loose panel walls are thrown out; decayed pilings brake off. Branches brake off trees. Changes in flow or in temperature of springs or wells. Cracks in wet ground and on steep slopes.

IX General panic. Masonry D structures destroyed, masonry C heavily damaged, sometimes completely collapsed. General damage to foundations. Frame structures, if not bolted, shift off their foundations. Serious damage to reservoirs. Underground pipes are broken. Conspicuous cracks in the ground. In alluvial areas, sand and mud are ejected forming sand craters.

X Most masonry and frame structures are destroyed. Most foundations destroyed. Some well-built wooden structures and bridges are destroyed. Serious damage to dams, dikes, and embankments. Underground pipelines are seriously damaged. Large landslides. Water thrown on banks of canals, river, lakes, etc. Sand and mud shifted horizontally on beaches, and in flatlands. Rails bent slightly.

XI Rails bent greatly. Underground pipelines completely out of service. Many and widespread disturbances of the ground, including broad fissures, earth slumps and land slips in soft, wet ground. Sand- and mud-charged water ejected from fissures in the ground. Sea-waves (tidal waves or tsunami) of significant magnitude. Severe damage to wood-frame structures, especially if near to the shock center. Severe damage to dams, dikes and embankments. Few, if any, masonry structures remain standing. Large, well-constructed bridges destroyed due to damage to their supporting piers or pillars. Wooden bridges are affected less.

XII Damage is nearly total. Lines of sight and level are distorted. Objects are thrown into the air. Great and varied disturbances of the ground, including numerous shearing cracks, landslides, large rockfalls, and numerous and widespread slumping of river banks. Fault slips in firm rock with notable horizontal and vertical offset. Water channels, both at the surface and underground are disturbed and modified. Lakes are dammed, rivers are deflected, waterfalls occur. The rolling effect of the seismic waves is actually seen at the ground surface.

Masonry A: Good workmanship, mortar and design. Reinforced, especially laterally, and bound together with steel, concrete, etc. Designed to resist lateral forces.

Masonry B: Good workmanship and mortar. Reinforced, but not designed to resist lateral forces.

Masonry C: Ordinary workmanship and mortar. Not reinforced or designed to resist horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar. Low standards of workmanship; weak horizontally.

These masonry types are not to be confused with the conventional Class A, B, and C construction types.

* Modified and rewritten after Richter (1958) and Toppozada and others (1988) using Rossi-Forel's Intensity Scale.

Predicting Ground Motion

Ground motion caused by earthquakes is generally characterized using the parameters of ground displacement, velocity, and acceleration. Engineers traditionally work with ground acceleration, rather than with velocity or displacement, since acceleration is directly related to the dynamic forces that earthquakes induce on structures. The most often used measure of the strength of ground motion is peak ground acceleration. Peak ground accelerations are generally calculated using empirical attenuation equations that describe the behavior of the ground motions as a function of the magnitude of the earthquake, and the distance between the site and the seismic source (the causative fault). The increasingly larger pool of seismic data recorded in the world, and particularly in the western United States, has allowed researchers to develop reliable empirical attenuation equations that are used to model the ground motions generated during an earthquake.

Although computer models are now routinely used to predict the ground motions expected at a given site as a result of an earthquake, it is still difficult to anticipate the damage sustained by different types of structures during an earthquake. This is so because the response of structures to ground shaking depends on many parameters, including the amplitude and frequency content of the seismic waves, and the duration of shaking. The frequency content of the ground motion, in turn, depends on the rupture mechanism of the earthquake, the properties of the materials that attenuate the seismic energy, and the regional and local site conditions that may amplify, focus, or defocus the seismic waves arriving at the site of interest. In addition, different structures, because of differences in their natural frequencies and modes of vibration, respond differently to a given ground motion. For planning purposes, therefore, it is generally best to study the effects of the worst-case scenario, using as standard the maximum credible earthquake of the fault with the highest probability of generating an earthquake, or the fault nearest to the site. Structures are then designed accordingly, assuming that earthquakes of lesser magnitude and intensity will effect less the study area.

Four earthquake scenarios have been modeled for this study to predict the strong ground motions, represented as peak ground accelerations, and the seismic intensities that would occur in Santa Monica as a result of maximum credible earthquakes on the San Andreas, Newport-Inglewood, Santa Monica, and Malibu Coast faults. The San Andreas and Newport-Inglewood earthquake scenarios were selected because they represent the most likely earthquakes to impact the City. The Santa Monica and Malibu Coast earthquake scenarios represent the absolute worse-case scenarios for the City. The ground shaking and seismic intensity maps presented in this report, if used together with inventories of potentially hazardous buildings, can help identify areas most likely to be severely damaged during an earthquake. The maps can also be used to identify areas where response capability operations, such as heavy rescue operations, will be vital in the case of an earthquake. The seismic intensity maps should be used only for general planning purposes, and should not be used for specific building design requirements. Boundaries between the stippled patterns on these figures are purposely not shown to prevent the false impression that spatial changes in predicted acceleration are abrupt, rather than gradual. Site-specific studies are required to adequately characterize the seismic parameters used in the design of a structure.

The intensity maps for the City were developed based on a combination of Richter's (1958) and Evernden and Thompson's (1988) empirical relationships for predicting intensity in terms of peak and root-mean-square (RMS) accelerations. Evernden and Thompson (1988) made a comprehensive study on the correlation between intensity and different seismic parameters. The results of their study indicate that RMS acceleration amplitudes and intensity show a better correlation than peak acceleration and intensity. However, most recent attenuation equations predict peak ground acceleration in terms of magnitude and distance. It was assumed that RMS acceleration amplitudes for alluvial sites are about 70% of the corresponding peak ground acceleration values. This choice was based on two considerations; 1) that by using this value of Richter's (1958) peak acceleration-intensity relationship agrees well with Evernden and Thompson's RMS amplitude-intensity relationship, and 2) that the estimated intensity values based on these equations are assumed to represent sites with alluvial conditions. The ratios of the RMS to peak amplitude for alluvial sites usually are higher than the ratios of the RMS to peak amplitude for alluvial sites are usually higher than the ratios for stiff soil or rock sites. This is also consistent with Evernden and Thompson's (1988) recommendation of negative corrections for intensity scales for sites that are not underlain by alluvial materials. However, it could be argued that the choice of a 70% ratio would result in an upper bound estimate of the RMS acceleration amplitudes based on peak ground accelerations.

Richter (1958) reported an acceleration-intensity relationship based on the Modified Mercalli Intensity scale. Evernden and Thompson (1988) stated that Modified Mercalli Intensities are not a linear scale in terms of the level of ground shaking. they argued that the Rossi-Forel scale provides a better linear relationship. However, this observation and the relation between the two scales are qualitative. The results reported here are based on both Richter's (1958) and Evernden and Thompson's (1988) empirical acceleration-intensity relationships.

Peak horizontal ground accelerations generated by the earthquake scenarios were estimated using Campbell's (1988) attenuation equation. Campbell's attenuation equation is based on data from 25 shallow earthquakes, most of which occurred in California. Campbell's database also includes several near-field earthquakes, similar to the earthquakes modeled in this study for the City of Santa Monica for the Newport-Inglewood, Santa Monica and Malibu Coast faults. The amplitude of the peak ground motion at any given location depends specifically on the faulting mechanism of the causative earthquake, and on the local site conditions. Only in recent years have there been enough recordings of strong ground motions from large earthquakes of different types of faulting mechanisms to quantify, in simple terms, the effects that the source mechanism and the site conditions have on the peak ground motions.

Campbell (1981; 1988) has reported that reverse faults generate higher peak ground accelerations, by a factor of 1.4, than those generated by strike-slip faults. These observations have been supported by Anderson and Luco (1983), who determined that sites located directly above the rupture surface of reverse faults experience amplitudes higher than those developed from any other rupture configuration. Joyner and Boore (1988) have also determined that peak horizontal accelerations from shallow reverse-slip earthquakes are, on average, 1.25 times higher than those generated by strike-slip faults. The Santa Monica and Malibu Coast faults are generally modeled as reverse faults, therefore, the peak ground acceleration and seismic intensity maps developed for these faults are based on Campbell's attenuation equation, with and without the correction factor for faulting mechanism. The San Andreas and Newport-Inglewood faults are modeled as strike-slip faults; the correction factor does not apply to the modeling of these faults.

The earthquake scenarios presented are for the maximum credible earthquake on each fault, that is, the fault is assumed to rupture along its entire length during the earthquake. All faults were modeled as a two-dimensional planar surface, called the seismogenic zone, dipping at an angle of 60 to 90 degrees. The four earthquake scenario faults were modeled with their seismogenic zones terminating at a depth of less than one-mile below the ground surface. The calculated peak ground accelerations are based on the closest distance between the site and the seismogenic zone of each fault modeled.

The seismic intensity maps were generated by dividing into grids a square that contains the City, 30 grids to each side. Each grid was assigned the ground condition that best represents that local area based on the geologic map of the Beverly Hills and south one-half Van Nuys quadrangles (Dibblee, 1991) (see Figure 2.2). The Modified Mercalli intensity value at each grid was calculated using Richter's (1958) empirical relationship for the Modified Mercalli intensity scale in terms of peak acceleration. The effect of the ground conditions on the intensity values was incorporated into the analysis using the correction values as recommended by Evernden and Thompson (1988).

The Modified Mercalli intensity scale is not defined in half-units. In this report, however, since intensities were calculated based on peak ground accelerations, the seismic intensity maps show intensity values in half units. This reflects the effect of mathematically converting acceleration values to intensity values, with half units interpreted as the intermediate values between full units of the intensity scale. A seismic intensity value of 8.5 includes calculated values ranging from 8.5 to 8.8, for example, rather than rounding off to level IX. The use of half-units in presenting intensity values is not meant as an attempt to introduce a new concept in seismic intensity values, but rather, as a means to present data obtained from mathematical models rather than from direct observation.

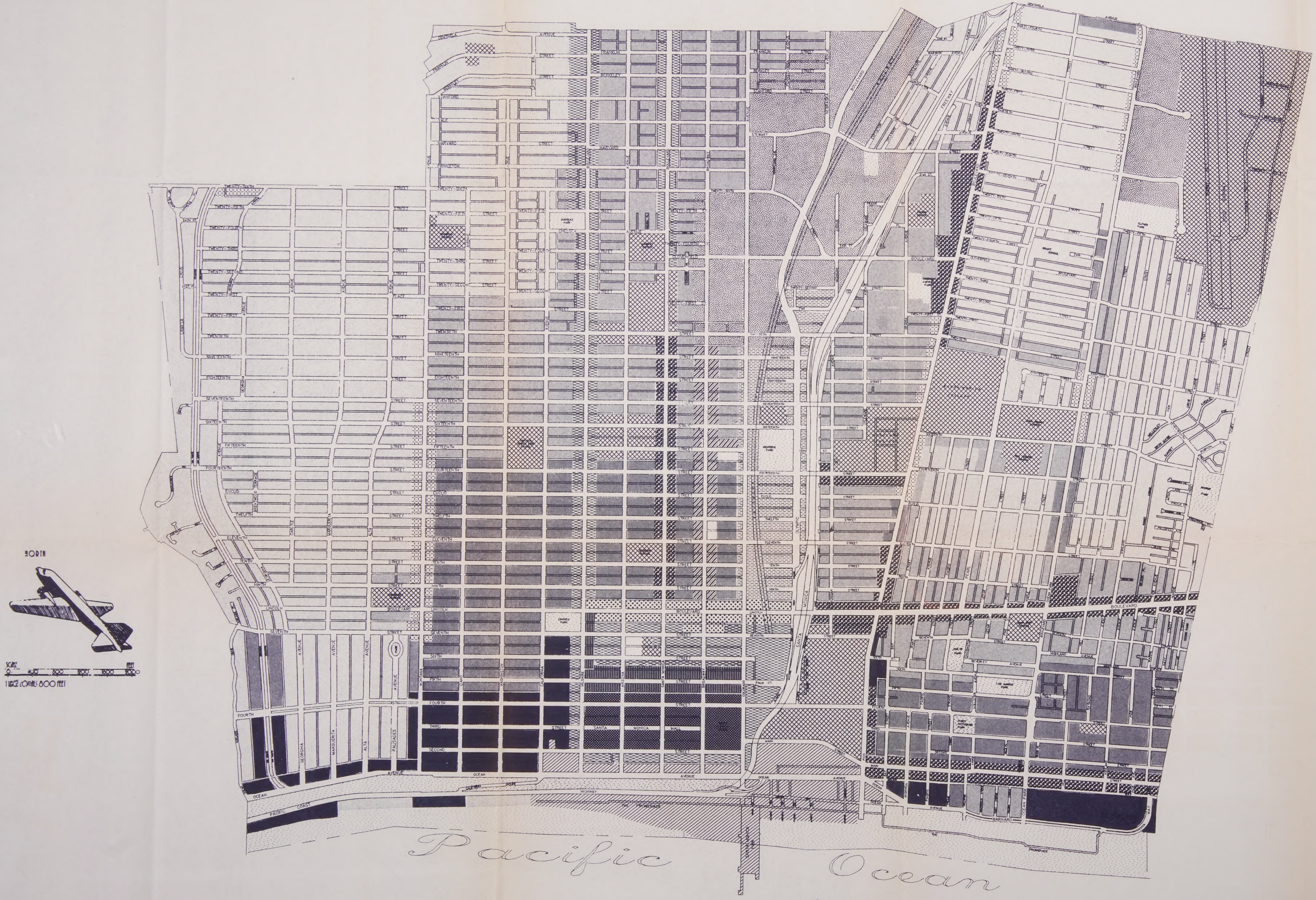
Shallow ground water can increase the expected seismic intensity values at a site. For most earthquake scenarios presented in this report, seismic intensity values increased by one level in those areas of the City where shallow ground water has been reported

(Figure 1.2). The accuracy of these interpretations is dependent on the accuracy of the ground water data available for Santa Monica. An increase of one level in the expected seismic intensities for a given scenario earthquake may be applied to any area of the City where shallow ground water (less than 30 feet) may be reported in the future. The seismic intensity maps presented in this report do not incorporate the damaging effects of ground failure. In areas where ground failure might occur, seismic intensity values may increase by one or two levels. Areas of suspect ground failure in the event on a large magnitude near-field earthquake, including liquefaction and slope instability, are discussed further in this chapter, and in chapter 3, respectively.

San Andreas Fault

The San Andreas fault has the highest probability of rupturing along one or more of its southern California segments within the next 30 years; the Mojave-San Bernardino segment of this fault is expected to generate a magnitude 8.0 maximum credible earthquake. Because this segment of the San Andreas fault is about 40 miles at its closest point to Santa Monica, the effects in Santa Monica of such an earthquake would be characteristic of a far-field event. Far-field earthquake effects, such as site amplification, cannot be modeled accurately given the techniques available to date, therefore, the following discussion on the effects in Santa Monica from an earthquake on the San Andreas may be limited in scope.

Seismic intensities expected to occur in Santa Monica as a result of a magnitude 8.0 event on the combined Mojave-San Bernardino segments of the San Andreas fault range from upper level VI to low level VII, with areas where shallow ground water is present experiencing Modified Mercalli intensities up to one-half unit higher than level VII (see Figure 1.3). These predicted seismic intensities agree well with the Rossi-Forel seismic intensity values of VII and VIII (in areas of known shallow ground water, where the potential for ground failure is high) predicted to occur in Santa Monica as a result of a magnitude 8.3 earthquake on the south-central San Andreas fault (Davis et al., 1982). Peak ground accelerations caused by a magnitude 8.0 event are expected to attenuate with distance away from the fault, so that in Santa Monica values of 0.10g (g is the acceleration due to gravity, equal to 32 feet per second squared) would predominate (Figure 1.4). Peak ground accelerations, given similar ground conditions across the City, will be expected to decrease towards the west. Such an event would have an expected duration of shaking in Santa Monica of 50 seconds.


NORTH
SCALE
0
400
800
1200
1600
2000
FEET
1 INCH EQUALS 800 FEET
Pacific Ocean
LINCOLN BOULEVARD
OCEAN AVENUE
PACIFIC COAST HIGHWAY
SANTA MONICA MALL
SANTA MONICA FREEWAY
WILSHIRE BOULEVARD

▢ SINGLE FAMILY HOUSING
░ LOW DENSITY HOUSING
▒ MEDIUM DENSITY HOUSING
■ HIGH DENSITY HOUSING
▦ NEIGHBORHOOD COMMERCIAL
▩ SERVICE AND SPECIALTY COMMERCIAL
▩ DOWNTOWN CORE
▨ GENERAL COMMERCIAL
▦ SPECIAL OFFICE DISTRICT
▧ OCEANFRONT SPECIAL DISTRICT
▨ BROADWAY MIXED USE DISTRICT
▦ GENERAL COMMERCIAL WITH SERVICE/SPECIALTY
▥ GENERAL COMMERCIAL WITH DOWNTOWN CORE
░ INDUSTRIAL
▩ INSTITUTIONAL
▢ PARKS

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map 1

CITY OF SANTA MONICA

LAND USE PLAN

6/20/95

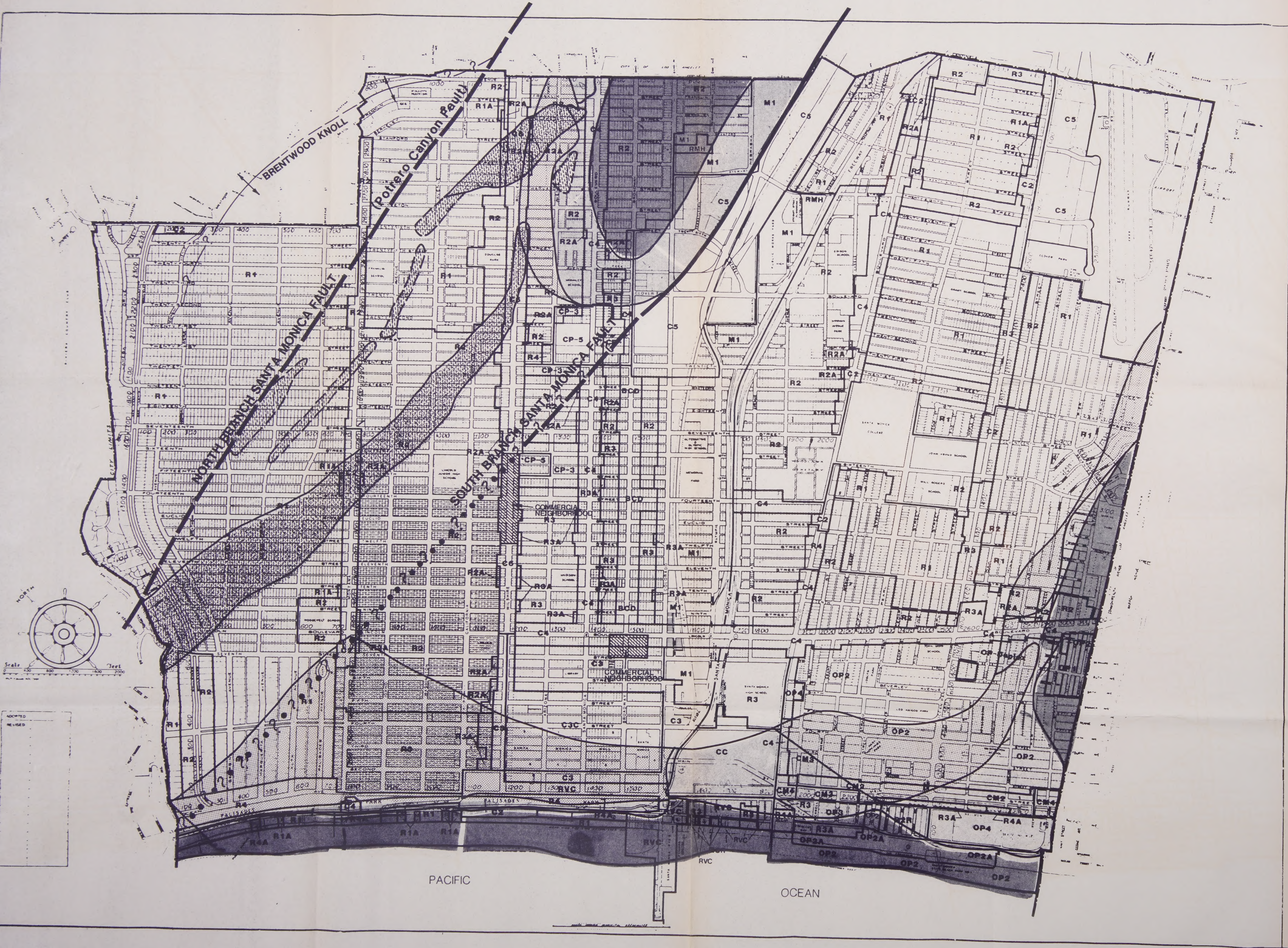


PLATE 1

Proj: 2910399-01	Scale: 1" = 800'	Date:
Engineer/Geologist: --/DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

SEISMIC HAZARDS: FAULT HAZARD MANAGEMENT ZONES AND LIQUEFACTION SUSCEPTIBILITY

Approximate Fault Location. Where considered well located using ground water barrier data, the faults are shown with a solid line, where moderately well located with dashed line, and where poorly located with a dotted and queried line.

FAULT SCARP. Topographic feature representing recent deformation of earth's surface due to faulting. Dark shading with solid border where features form relatively strong surface expressions, while lighter shading with dashed border represents features that form relatively weaker surface expressions.

Liquefaction Susceptibility:

■	**High**	▨	**Low**
▩	**Medium**	☐	**Very Low to None**

The limits of the liquefaction-prone areas are approximate. Due to the limited data available to compile this figure, this map should be used only for general planning purposes. Site-specific investigations should be conducted in areas with high, moderate and low liquefaction potential, if the proposed structure is a critical facility, and within high and moderate areas for projects greater than two-stories. *This figure should be amended as more data on depth to ground water and soil type and density are obtained.*

Sources:

Bailey, 1968
County of Los Angeles, 1990
Crook, et al., 1983
Dames and Moore, 1985
Hauksson, 1990
Lamar, 1978
Poland, et al., 1959
Dolan and Sieh, 1991; personal comm. 1991; 1992
City of Santa Monica, 1975; personal comm. 1991
Crandall and Associates, 1978; 1986; 1987; 1989; 1990
Hill, 1976; 1979; personal comm.1991
Leighton and Associates, 1987
Mendenhall, 1950
U.S. Geological Survey, 1985

ZONE DISTRICT	
R1	SINGLE-FAMILY RESIDENTIAL
R2R	LOW DENSITY RESIDENTIAL
R2	LOW DENSITY MULTI-FAMILY RESIDENTIAL
R3	MEDIUM DENSITY MULTI-FAMILY RESIDENTIAL
R4	HIGH DENSITY MULTI-FAMILY RESIDENTIAL
R-MH	RESIDENTIAL MOBILE HOME PARK
RVC	RESIDENTIAL-VISITOR COMMERCIAL
BCD	BROADWAY COMMERCIAL DISTRICT
C2	NEIGHBORHOOD COMMERCIAL
C3	DOWNTOWN COMMERCIAL
C3-C	DOWNTOWN OVERLAY
C4	HIGHWAY COMMERCIAL
C5	SPECIAL OFFICE COMMERCIAL
C6	BOULEVARD COMMERCIAL
CM	MAIN STREET SPECIAL COMMERCIAL
CP	COMMERCIAL PROFESSIONAL
CC	CIVIC CENTER
M1	INDUSTRIAL CONSERVATION
OP1	OCEAN PARK SINGLE-FAMILY
OP-Duplex	OCEAN PARK DUPLEX
OP2	OCEAN PARK LOW MULTI-FAMILY
OP3	OCEAN PARK MEDIUM MULTI-FAMILY
OP4	OCEAN PARK HIGH MULTI-FAMILY
R3R	MEDIUM DENSITY COASTAL RESIDENTIAL 2 STORY 1.0 F.A.R 1 UNIT PER 1250

OVERLAY DISTRICTS	
A	OFF-STREET PARKING
PL	PUBLIC LANDS
▨ N	NEIGHBORHOOD COMMERCIAL
▤ NW	NORTH OF WILSHIRE

CITY OF SANTA MONICA OFFICIAL DISTRICTING MAP

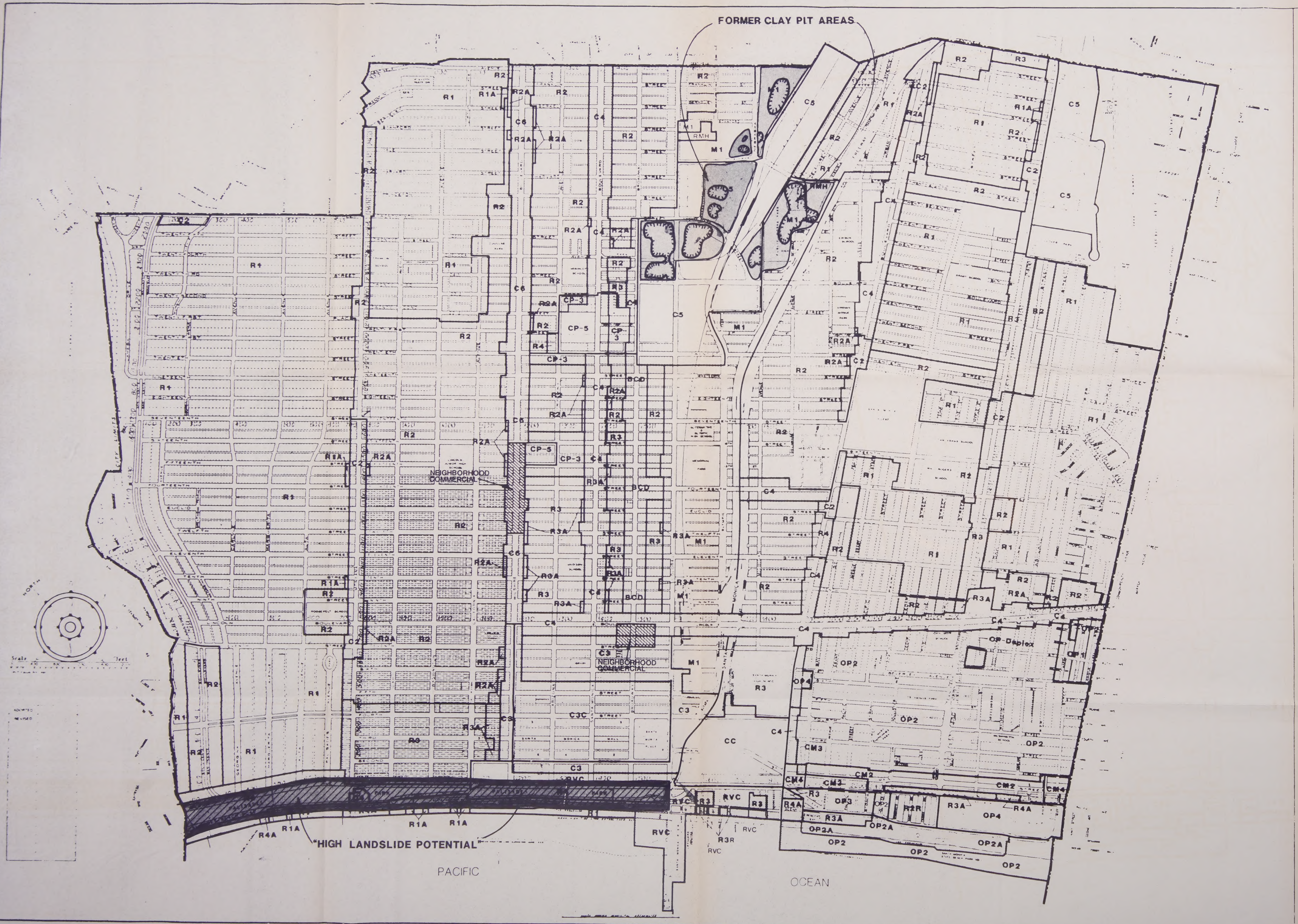
00 0161
map 3

PLATE 2

Proj: 2910399-01	Scale: 1" = 800'	Date:
Engineer/Geologist: --'DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

GEOLOGIC HAZARDS: ABANDONED CLAY PITS AND LANDFILLS, AND SLOPE INSTABILITY


FORMER CLAY PIT AREAS
HIGH LANDSLIDE POTENTIAL
NEIGHBORHOOD COMMERCIAL
PACIFIC
OCEAN
NORTH
Scale
Feet
R1
R1A
R2
R2A
R2R
R3
R3A
R3R
R4
R4A
RMH
RVC
BCD
C2
C3
C3C
C4
C5
C6
CM2
CM3
CM4
CP-3
CP-5
CC
M1
OP1
OP-Duplex
OP2
OP2A
OP3
OP4

ZONE DISTRICT

R1	SINGLE-FAMILY RESIDENTIAL
R2R	LOW DENSITY RESIDENTIAL
R2	LOW DENSITY MULTI-FAMILY RESIDENTIAL
R3	MEDIUM DENSITY MULTI-FAMILY RESIDENTIAL
R4	HIGH DENSITY MULTI-FAMILY RESIDENTIAL
R-MH	RESIDENTIAL MOBILE HOME PARK
RVC	RESIDENTIAL-VISITOR COMMERCIAL
BCD	BROADWAY COMMERCIAL DISTRICT
C2	NEIGHBORHOOD COMMERCIAL
C3	DOWNTOWN COMMERCIAL
C3-C	DOWNTOWN OVERLAY
C4	HIGHWAY COMMERCIAL
C5	SPECIAL OFFICE COMMERCIAL
C6	BOULEVARD COMMERCIAL
CM	MAIN STREET SPECIAL COMMERCIAL
CP	COMMERCIAL PROFESSIONAL
CC	CIVIC CENTER
M1	INDUSTRIAL CONSERVATION
OP1	OCEAN PARK SINGLE-FAMILY
OP-Duplex	OCEAN PARK DUPLEX
OP2	OCEAN PARK LOW MULTI-FAMILY
OP3	OCEAN PARK MEDIUM MULTI-FAMILY
OP4	OCEAN PARK HIGH MULTI-FAMILY
R3R	MEDIUM DENSITY COASTAL RESIDENTIAL 2 STORY 1.0 F.A.R. 1 UNIT PER 1250

OVERLAY DISTRICTS

A	OFF-STREET PARKING
PL	PUBLIC LANDS
▨ N	NEIGHBORHOOD COMMERCIAL
░ NW	NORTH OF WILSHIRE

CITY OF SANTA MONICA

OFFICIAL DISTRICTING MAP

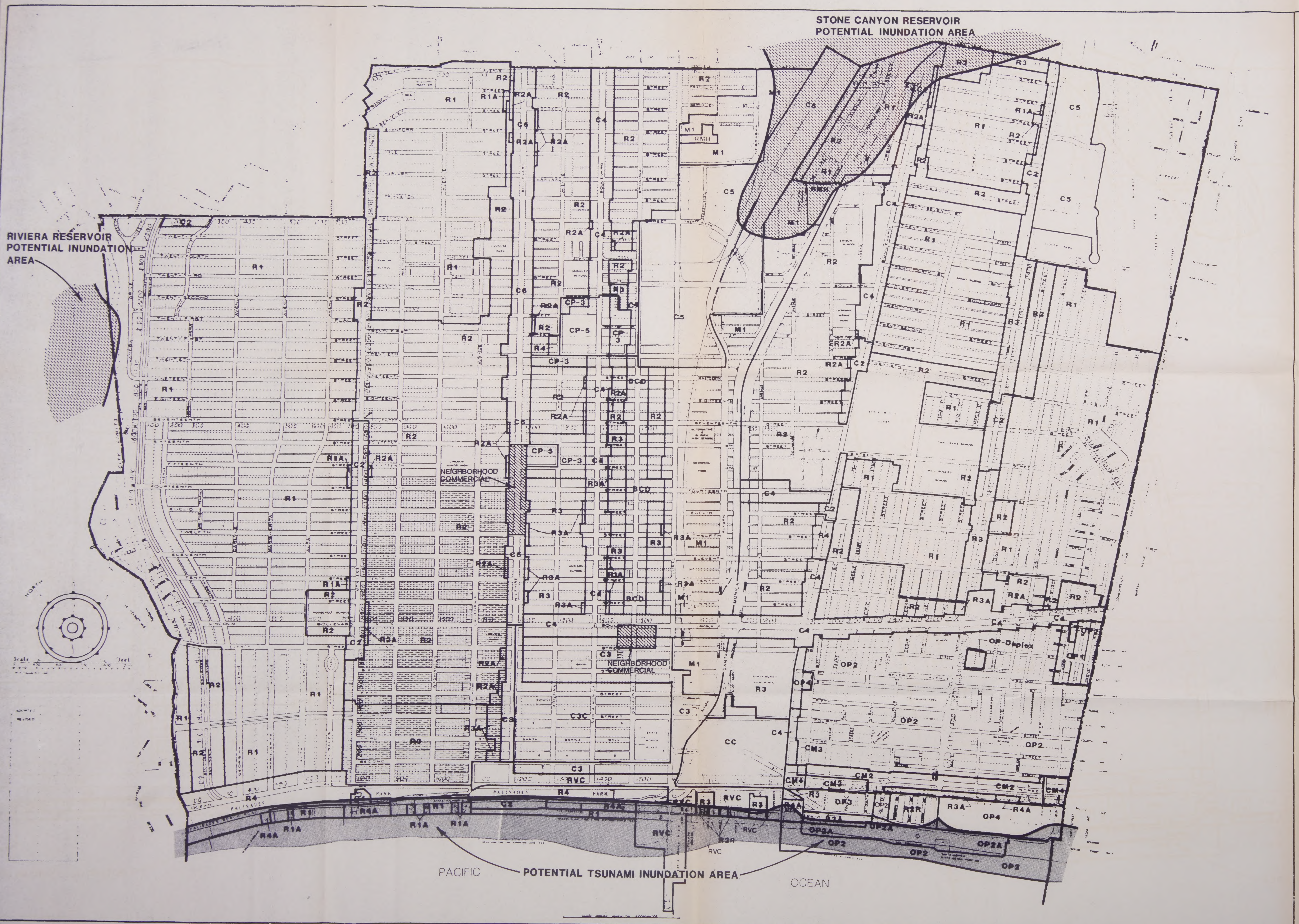

STONE CANYON RESERVOIR
POTENTIAL INUNDATION AREA
RIVIERA RESERVOIR
POTENTIAL INUNDATION
AREA
NEIGHBORHOOD COMMERCIAL
NEIGHBORHOOD COMMERCIAL
PACIFIC
POTENTIAL TSUNAMI INUNDATION AREA
OCEAN
NORTH
Scale
Feet
R1
R1A
R2
R2A
R3
R3A
R4
R4A
RMH
RVC
BCD
C2
C3
C3C
C4
C5
C6
CP-3
CP-5
CC
CM2
CM3
CM4
M1
OP2
OP2A
OP3
OP3A
OP4
OP-Duplex
R2R
R3R

PLATE 3

Proj: 2910399-01	Scale: 1" = 800'	Date:
Engineer/Geologist: --/DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

INUNDATION HAZARDS: DAM FAILURE INUNDATION PATHS AND TSUNAMI RUNUP

▨ **Potential Dam Inundation Limits for Stone Canyon and Riviera Reservoirs.** Government Code Section 8589.5 requires owners of dams to prepare dam inundation maps and emergency response plans. Use of this map should be limited to evacuation and general urban planning purposes only.

▒ **Potential Tsunami Inundation Area.** This area reflects the worst-case scenario for the City, with tsunami run-up heights of about 16.6 feet, as modeled by Houston and Garcia (1974) for a 500-year tsunami event generated along the Aleutian-Alaskan trench. The run-up heights presented herein also include the effect of astronomical tides. Near-field sources for tsunami were not considered in this analysis.

Sources:
City of Los Angeles Department of Water and Power, 1975
Delta Consulting Engineers, 1974
Houston and Garcia, 1974

ZONE DISTRICT

R1	SINGLE-FAMILY RESIDENTIAL
R2R	LOW DENSITY RESIDENTIAL
R2	LOW DENSITY MULTI-FAMILY RESIDENTIAL
R3	MEDIUM DENSITY MULTI-FAMILY RESIDENTIAL
R4	HIGH DENSITY MULTI-FAMILY RESIDENTIAL
R-MH	RESIDENTIAL MOBILE HOME PARK
RVC	RESIDENTIAL-VISITOR COMMERCIAL
BCD	BROADWAY COMMERCIAL DISTRICT
C2	NEIGHBORHOOD COMMERCIAL
C3	DOWNTOWN COMMERCIAL
C3-C	DOWNTOWN OVERLAY
C4	HIGHWAY COMMERCIAL
C5	SPECIAL OFFICE COMMERCIAL
C6	BOULEVARD COMMERCIAL
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CP	COMMERCIAL PROFESSIONAL
CC	CIVIC CENTER
M1	INDUSTRIAL CONSERVATION
OP1	OCEAN PARK SINGLE-FAMILY
OP-Duplex	OCEAN PARK DUPLEX
OP2	OCEAN PARK LOW MULTI-FAMILY
OP3	OCEAN PARK MEDIUM MULTI-FAMILY
OP4	OCEAN PARK HIGH MULTI-FAMILY
R3R	MEDIUM DENSITY COASTAL RESIDENTIAL 2 STORY 1.0 F.A.R. 1 UNIT PER 1250

OVERLAY DISTRICTS

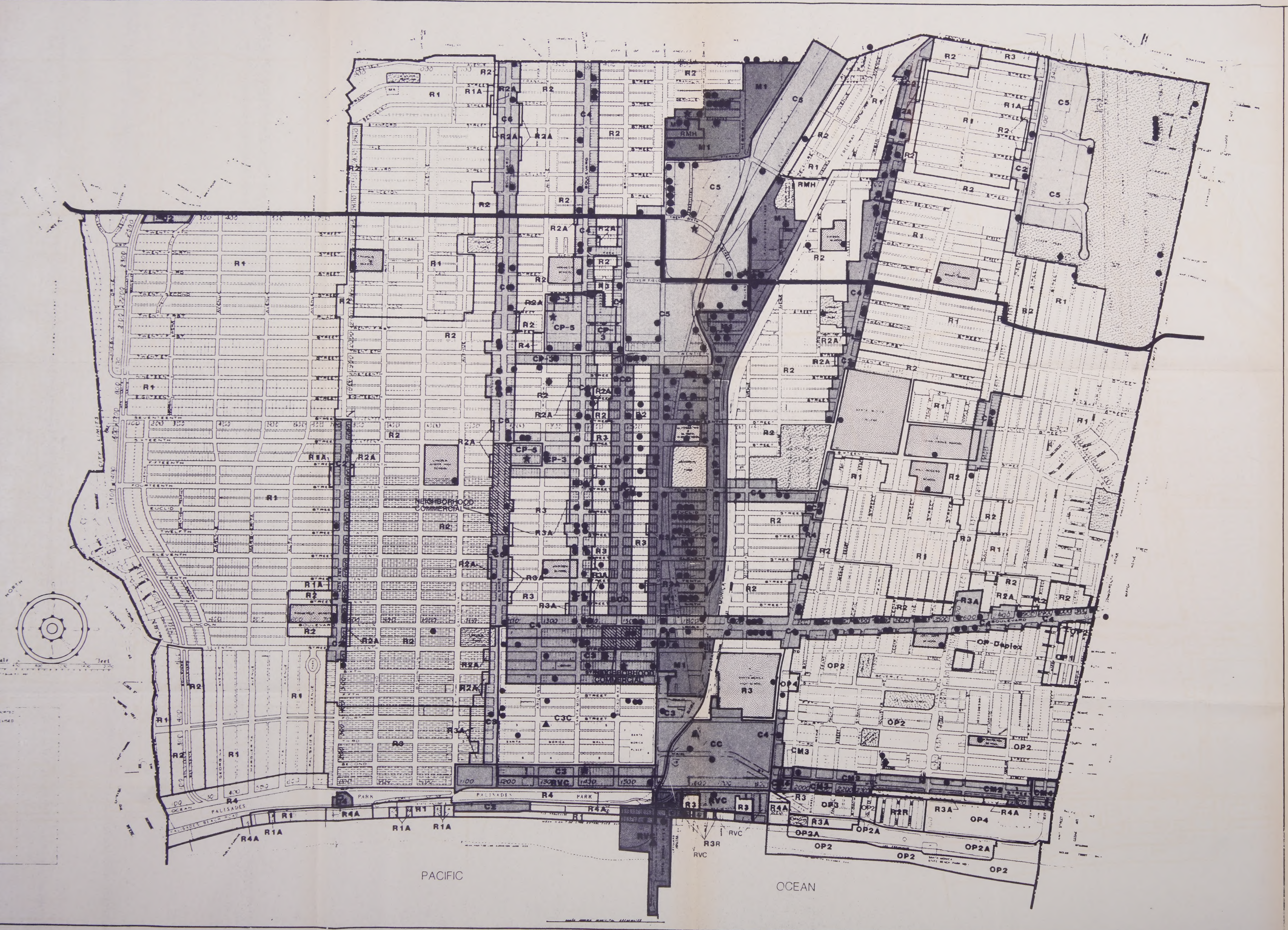
A	OFF-STREET PARKING
PL	PUBLIC LANDS
▨ N	NEIGHBORHOOD COMMERCIAL
NW	NORTH OF WILSHIRE

CITY OF
SANTA MONICA

OFFICIAL DISTRICTING MAP

map 5

PLATE 4



Proj: 2910399-01	Scale: 1"=800'	Date:
Engineer/Geologist: --/DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

ZONE DISTRICTS AND FACILITIES USING HAZARDOUS MATERIALS

▨	Manufacturing Zone Districts
☐	Commercial Zone Districts
▨	Schools
▨	Parks, Cemetery, Airport, Reservoirs
◆	Fire Stations
▲	Police Stations. The Emergency Operation Center (EOC) is located in the basement of the Main Police Station.
★	Facilities that use Extremely Hazardous Materials
●	Facilities that use Hazardous Materials in quantities over threshold limits
━	Crude oil pipeline

Sources:

City of Santa Monica, 1990, Draft Hazardous Material Incident Contingency Plan.
City of Santa Monica, Draft Official Districting Map, undated.
City of Santa Monica, Environmental Division, Listing of businesses reporting hazardous Materials over threshold limits, undated.

ZONE DISTRICT

R1	SINGLE-FAMILY RESIDENTIAL
R2R	LOW DENSITY RESIDENTIAL
R2	LOW DENSITY MULTI-FAMILY RESIDENTIAL
R3	MEDIUM DENSITY MULTI-FAMILY RESIDENTIAL
R4	HIGH DENSITY MULTI-FAMILY RESIDENTIAL
R-MH	RESIDENTIAL MOBILE HOME PARK
RVC	RESIDENTIAL-VISITOR COMMERCIAL
BCD	BROADWAY COMMERCIAL DISTRICT
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C3-C	DOWNTOWN OVERLAY
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CC	CIVIC CENTER
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OP1	OCEAN PARK SINGLE-FAMILY
OP-Duplex	OCEAN PARK DUPLEX
OP2	OCEAN PARK LOW MULTI-FAMILY
OP3	OCEAN PARK MEDIUM MULTI-FAMILY
OP4	OCEAN PARK HIGH MULTI-FAMILY
R3R	MEDIUM DENSITY COASTAL RESIDENTIAL 2 STORY 1.0 F.A.R. 1 UNIT PER 1250

OVERLAY DISTRICTS

A	OFF-STREET PARKING
PL	PUBLIC LANDS
▨ N	NEIGHBORHOOD COMMERCIAL
▨ NW	NORTH OF WILSHIRE

CITY OF SANTA MONICA

OFFICIAL DISTRICTING MAP

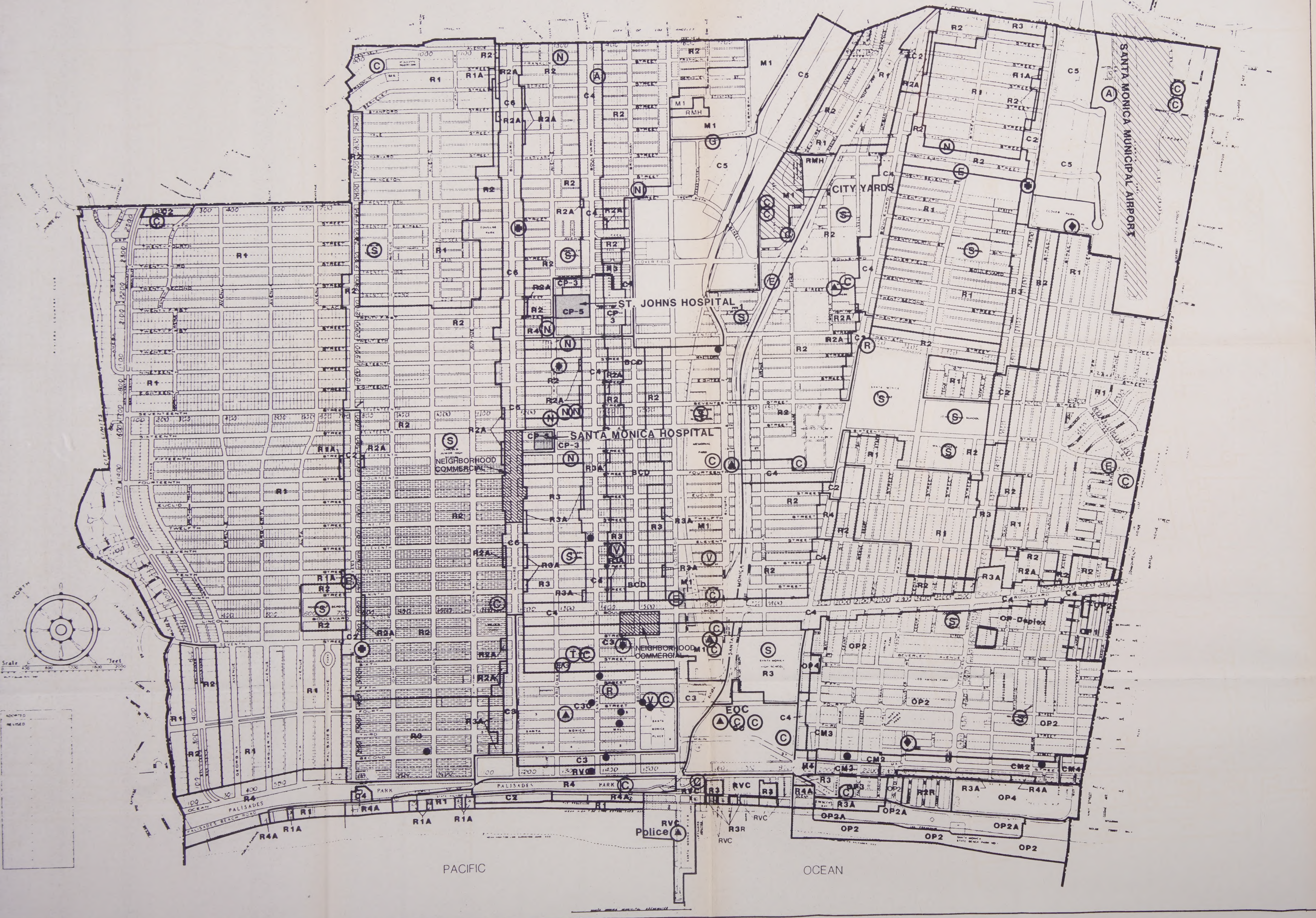


PLATE 5

Proj: 2910399-01	Scale: 1"=800'	Date:
Engineer/Geologist: --/DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

SELECTED CRITICAL FACILITIES

TIER I

- Ⓒ City Facilities
- ▲ Police Stations The Emergency Operation Center (EOC) is located in the basement of the Main Police Station.
- ◆ Fire Stations

TIER II - *NOT PLOTTED ON THIS MAP*

TIER III

- Ⓐ Ambulance Services
- ▨ Acute Care Hospitals
- ⊕ Urgent Care Medical Facilities
- Ⓝ Nursing Homes (Dependent Care Facilities)
- Ⓢ Schools
- Ⓔ Southern California Edison
- Ⓖ Southern California Gas Co.
- Ⓣ General Telephone Company
- Ⓡ Radio Stations
- ● High Risk Unreinforced Masonry Structures
- Ⓥ Volunteer Agencies (American Red Cross and Salvation Army)

Evacuation Shelters are shown on Plate 7.

Sources:
City of Santa Monica, 1989, Multi-Hazard Functional Plan
Envicom, 1975
Michael Brandman and Associates, 1991
Toppozada et al., 1988

CITY OF SANTA MONICA CRITICAL FACILITIES

TIER I

CITY FACILITIES: Ⓒ	
Airport Administration	3233 D. Douglas Loop, So.
Airport Specialty Hangars	3100 D. Douglas Loop, So.
Arcadia Water Treatment Plant	1228 South Bundy Los Angeles, CA 90025
Animal Shelter	1640 9th Street
Charnock Pumping Station	11375 Westminster Los Angeles, Ca 90066
City Hall Offices	1685 Main Street
Emergency Operations Center (E.O.C.)	1685 Main Street
City Yards	2500 Michigan Ave.
Civic Auditorium	1855 Main Street
Fire Training Center	2500 Michigan Ave.
Ken Edwards Center	1527 4th Street
Moss Ave. Sewer Pumping Sta.	1601 Appian Way
Mt. Olivette Reservoir	930 Franklin Street
Riviera G.C. Reservoir	1252 Capri Drive Brentwood, CA 90049
San Vicente Reservoir	201 25th Street
SM Municipal Bus Lines	1660 6th Street
Transfer Station	2401 Delaware Avenue
Transportation Building	1660 7th Street
Woodlawn Cemetery	1847 14th Street

POLICE FACILITIES: ▲	
Bicycle Substation	4th St. & Arizona Pkg. Structure #3
Harbor Guard Office	402 Santa Monica Pier
Police Activities League	1401 Olympic Blvd.
Police Station & Jail	1685 Main Street
Special Operations Office	1660 7th Street
Virginia Park Substation	2200 Virginia Ave.
FIRE STATIONS: ◆	
Santa Monica Fire Station #1 & Fire Dept. Headquarters	1444 7th Street
Santa Monica Fire Station #2	222 Hollister Avenue
Santa Monica Fire Station #3	1302 19th Street
Santa Monica Fire Station #5	2450 Ashland Ave.
LIBRARIES: Ⓒ	
Main Library	1343 6th Street
RECREATION AND PARK FACILITIES: Ⓒ	
Lincoln Park (except Miles Playhouse Senior Nutrition)	Lincoln & Wilshire Blvd. Lincoln & Wilshire Blvd.
Marine Park	16th St. & Marine Street
Memorial Park	14th St. & Olympic
Virginia Park	220 Virginia Avenue
Palisades Park Senior Recreation Center	Ocean & Colorado (North 1450 Ocean Avenue

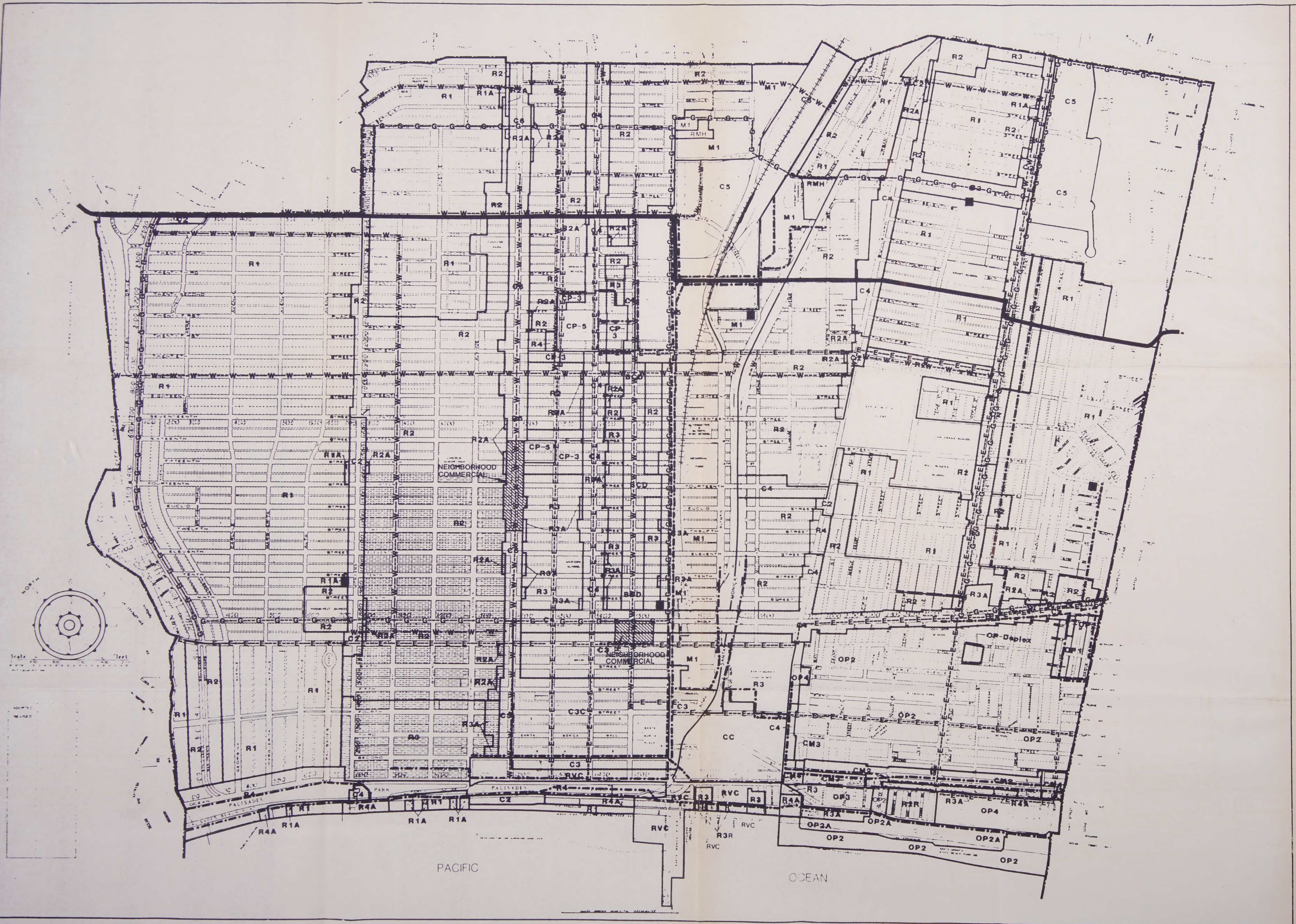
CITY OF SANTA MONICA
OFFICIAL DISTRICTING MAP

PLATE 6

Proj: 2910399-01	Scale: 1"=800'	Date:
Engineer/Geologist: --/DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

LIFELINE UTILITIES



PACIFIC
OCEAN
NEIGHBORHOOD COMMERCIAL
NEIGHBORHOOD COMMERCIAL
NORTH
Scale
Feet
R1
R1A
R2
R2A
R3
R3A
R4
R4A
RMH
RVC
C2
C3
C3C
C4
C5
C6
CP-3
CP-5
CC
CM2
CM3
M1
BCD
OP2
OP2A
OP3
OP4
OP-Duplex
R2R
R3R

W---W---W	Water Mains (36 to 14-inch pipes)
—·—·—·—	Sewer Mains (30 to 12-inch pipes)
G---G---G	Natural Gas Mains (12 to 16-inch pipes)
E---E---E	Major Electrical and Telephone Trunk Lines
▬	Crude Oil Pipeline (10-inch pipe)
++++++++++	Southern Pacific Railroad Line
■	Electrical Substation

Sources:
Envicom, 1975
Michael Brandman Associates, 1991
Toppozada et al., 1988

ZONE DISTRICT

R1	SINGLE-FAMILY RESIDENTIAL
R2R	LOW DENSITY RESIDFNTIAL
R2	LOW DENSITY MULTI-FAMILY RESIDENTIAL
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OP4	OCEAN PARK HIGH MULTI-FAMILY
R3R	MEDIUM DENSITY COASTAL RESIDENTIAL 2 STORY 1.0 F.A.R 1 UNIT PER 125C

OVERLAY DISTRICTS

A	OFF-STREET PARKING
PL	PUBLIC LANDS
▨ N	NEIGHBORHOOD COMMERCIAL
░ NW	NORTH OF WILSHIRE

CITY OF SANTA MONICA OFFICIAL DISTRICTING MAP

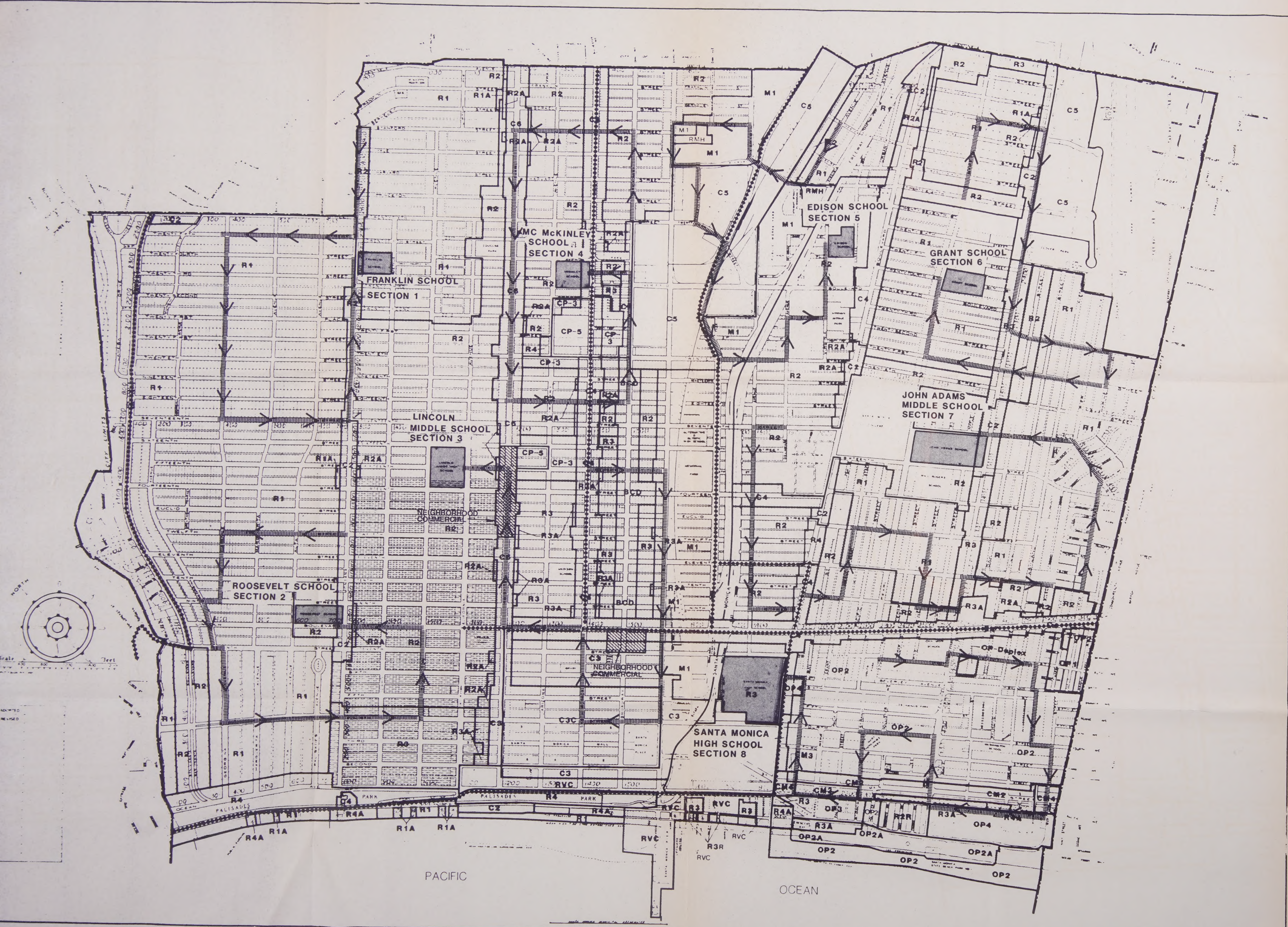
FRANKLIN SCHOOL
SECTION 1
ROOSEVELT SCHOOL
SECTION 2
LINCOLN
MIDDLE SCHOOL
SECTION 3
MC McKINLEY
SCHOOL
SECTION 4
EDISON SCHOOL
SECTION 5
GRANT SCHOOL
SECTION 6
JOHN ADAMS
MIDDLE SCHOOL
SECTION 7
SANTA MONICA
HIGH SCHOOL
SECTION 8
NEIGHBORHOOD
COMMERCIAL
PACIFIC
OCEAN
NORTH

PLATE 7

Proj: 2910399-01	Scale: 1"=800'	Date:
Engineer/Geologist: --/DB		Drafting By: nh

LEIGHTON AND ASSOCIATES, INC.

DISASTER ROUTES AND EMERGENCY EVACUATION TRANSPORTATION ROUTES

◆◆◆◆◆◆◆◆	County Disaster Routes
←	Emergency Evacuation Transportation Routes. Arrows indicate the direction in which the City has proposed to evacuate impacted neighborhoods in the event of a disaster.
▒	Emergency Evacuation Shelters

Sources:

Los Angeles County Department of Public Works, 1979, Disaster Routes in the Metropolitan Area of the County of Los Angeles

City of Santa Monica, 1989, Multi-Hazard Functional Plan

ZONE DISTRICT

R1	SINGLE-FAMILY RESIDENTIAL
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OP-Duplex	OCEAN PARK DUPLEX
OP2	OCEAN PARK LOW MULTI-FAMILY
OP3	OCEAN PARK MEDIUM MULTI-FAMILY
OP4	OCEAN PARK HIGH MULTI-FAMILY
R3R	MEDIUM DENSITY COASTAL RESIDENTIAL 2 STORY 1.0 F.A.R. 1 UNIT PER 1250

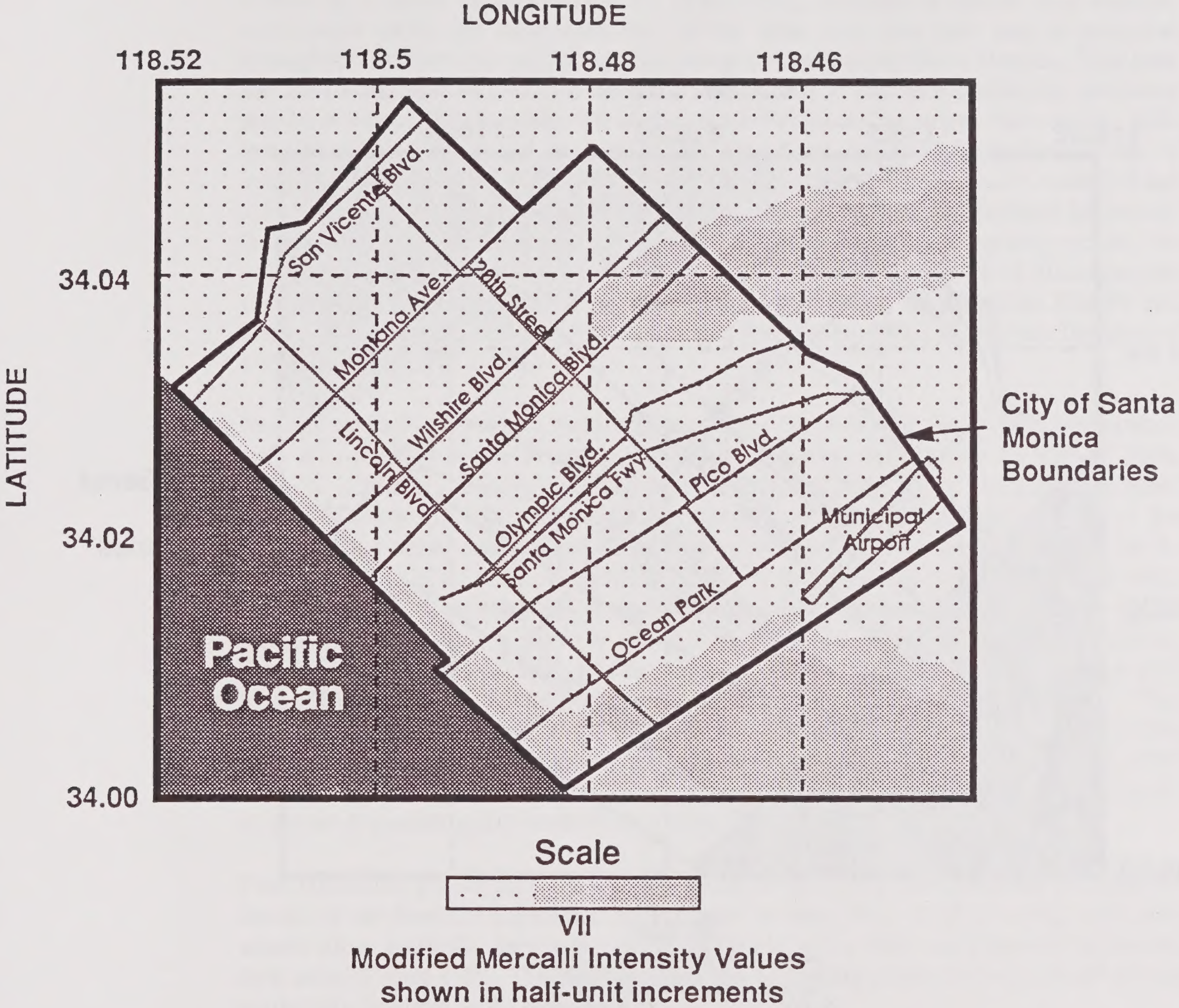
OVERLAY DISTRICTS

A	OFF-STREET PARKING
PL	PUBLIC LANDS
▨ N	NEIGHBORHOOD COMMERCIAL
▒ NW	NORTH OF WILSHIRE

CITY OF SANTA MONICA
OFFICIAL DISTRICTING MAP

Figure 1.3

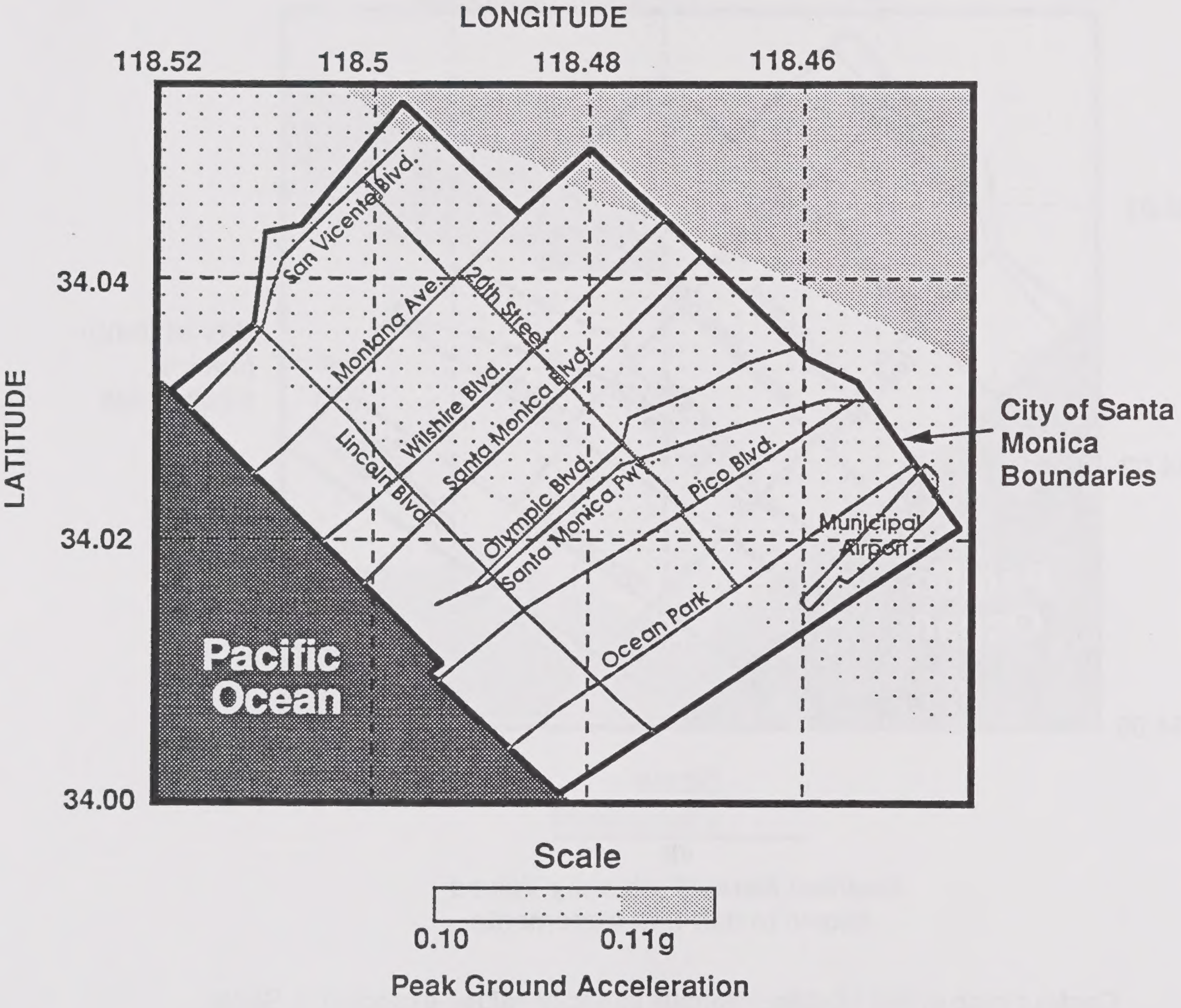
Modified Mercalli Intensities for a Magnitude 8.0 Earthquake on the Combined Mojave-San Bernardino segments of the San Andreas Fault


LONGITUDE
118.52
118.5
118.48
118.46
LATITUDE
34.04
34.02
34.00
San Vicente Blvd.
Montana Ave.
26th Street
Wilshire Blvd.
Santa Monica Blvd.
Lincoln Blvd.
Olympic Blvd.
Santa Monica Fwy.
Pico Blvd.
Ocean Park
Municipal Airport
Pacific Ocean
City of Santa Monica Boundaries
Scale
VII
Modified Mercalli Intensity Values shown in half-unit increments

Contour map of the Modified Mercalli Intensity values expected in Santa Monica from an earthquake of Magnitude 8.0 rupturing both the Mojave-San Bernardino segment of the San Andreas fault. Half intensity units represent the upper half unit of each intensity value. The boundaries between each unit represent a smooth variation in intensity, and should not be taken to be as sharply as herein defined.

Figure 1.4

Peak Horizontal Ground Accelerations for a Magnitude 8.0 Earthquake on the Combined Mojave-San Bernardino segments of the San Andreas Fault


LONGITUDE
118.52
118.5
118.48
118.46
LATITUDE
34.04
34.02
34.00
San Vicente Blvd.
Montana Ave.
20th Street
Wilshire Blvd.
Santa Monica Blvd.
Lincoln Blvd.
Olympic Blvd.
Santa Monica Fwy.
Pico Blvd.
Ocean Park
Municipal Airport
Pacific Ocean
City of Santa Monica Boundaries
Scale
0.10
0.11g
Peak Ground Acceleration

Contour map of the peak ground acceleration values (g) expected in Santa Monica from an earthquake of Magnitude 8.0 rupturing both the Mojave-San Bernardino segment of the San Andreas fault.

Newport-Inglewood Fault

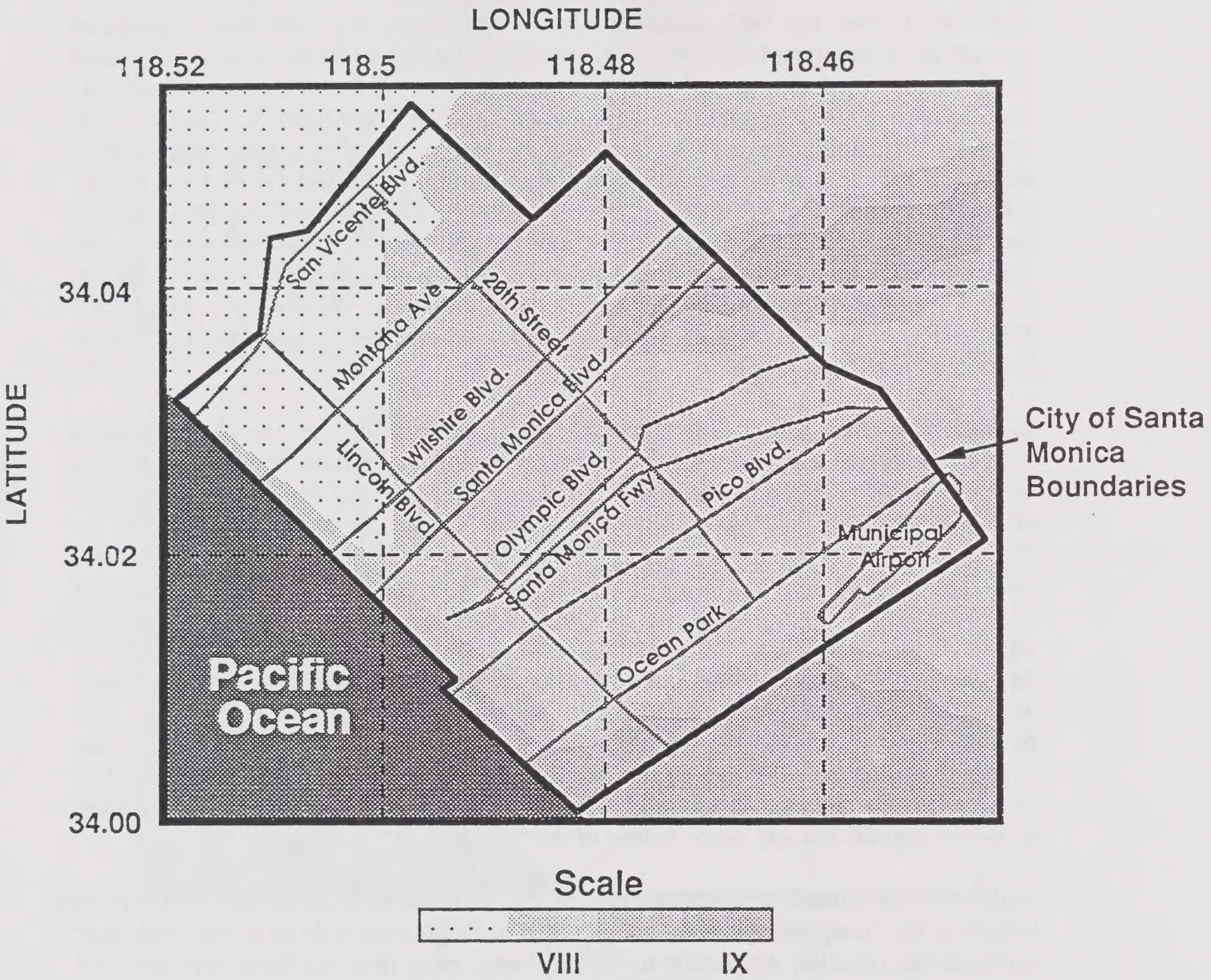
The onshore Newport-Inglewood fault zone extends from Newport Beach northwesterly through the Los Angeles Basin to the Cheviot Hills, and northward to the Hollywood fault zone north of the Beverly Hills area. The fault zone, which is expressed at the surface by a series of hills formed by drag-folding, consists of several near-vertical, right-lateral strike slip fault segments. In the study area, the fault zone is projected through the northern part of Culver City, about 6 miles east of Santa Monica. This fault has been associated with several historical earthquakes in southern California, including the December 8, 1812 intensity VII earthquake in San Juan Capistrano, the June 21, 1920 intensity VIII earthquake in Inglewood, and the March 10, 1933 Long Beach event of magnitude 6.3. In addition, several moderate earthquakes of magnitudes between 2.5 and 5.4, and hundreds of micro-tremors, have been associated with the Newport-Inglewood fault zone since 1933. The fault is considered active given its seismicity record, the youthful geomorphic features along the fault, and based on evidence of Holocene-age surface ruptures documented in Orange County by various investigators (Guptil and Heath, 1981; Medal, Aragon, Worswick, and Associates,. 1981; California Division of Mines and Geology, 1986).

Because of its high level of historical seismicity, an event on the Newport-Inglewood fault is considered the most probable event for planning purposes in the City of Santa Monica. Figure 1.5 shows a seismic intensity map for the City of Santa Monica based on a maximum credible earthquake of magnitude 6.8 on the northern branch of the Newport-Inglewood fault. Seismic intensities are predicted to range from VIII in the central portions of the City, to levels above IX in the areas where shallow ground water conditions have been reported. Local geologic conditions are known to influence the effect of ground motion, and to affect how structures respond to ground shaking. Saturated, soft, poorly-consolidated deposits, such as the beach deposits along the coastal area of Santa Monica, are known to amplify earthquake-induced ground motions. This phenomenon was responsible for much of the damage in the Marina District of San Francisco during the 1989 Loma Prieta Earthquake, and in Mexico City during the 1985 Mexico City Earthquake. In addition, ridge-top focusing along the bluff will likely result in severe degradation and block failure of the bluff top.

Peak horizontal ground accelerations in the City as a result of such an event on the north branch of the Newport-Inglewood are expected to range from 0.25 to 0.35g, with peak accelerations generally decreasing to the northwest, away from the Newport-Inglewood fault zone (Figure 1.6). The expected duration of shaking in the City as a result of this earthquake scenario is 22 seconds.

Figure 1.5

Modified Mercalli Intensities for a Magnitude 6.8 Earthquake on the North Branch of the Newport-Inglewood Fault

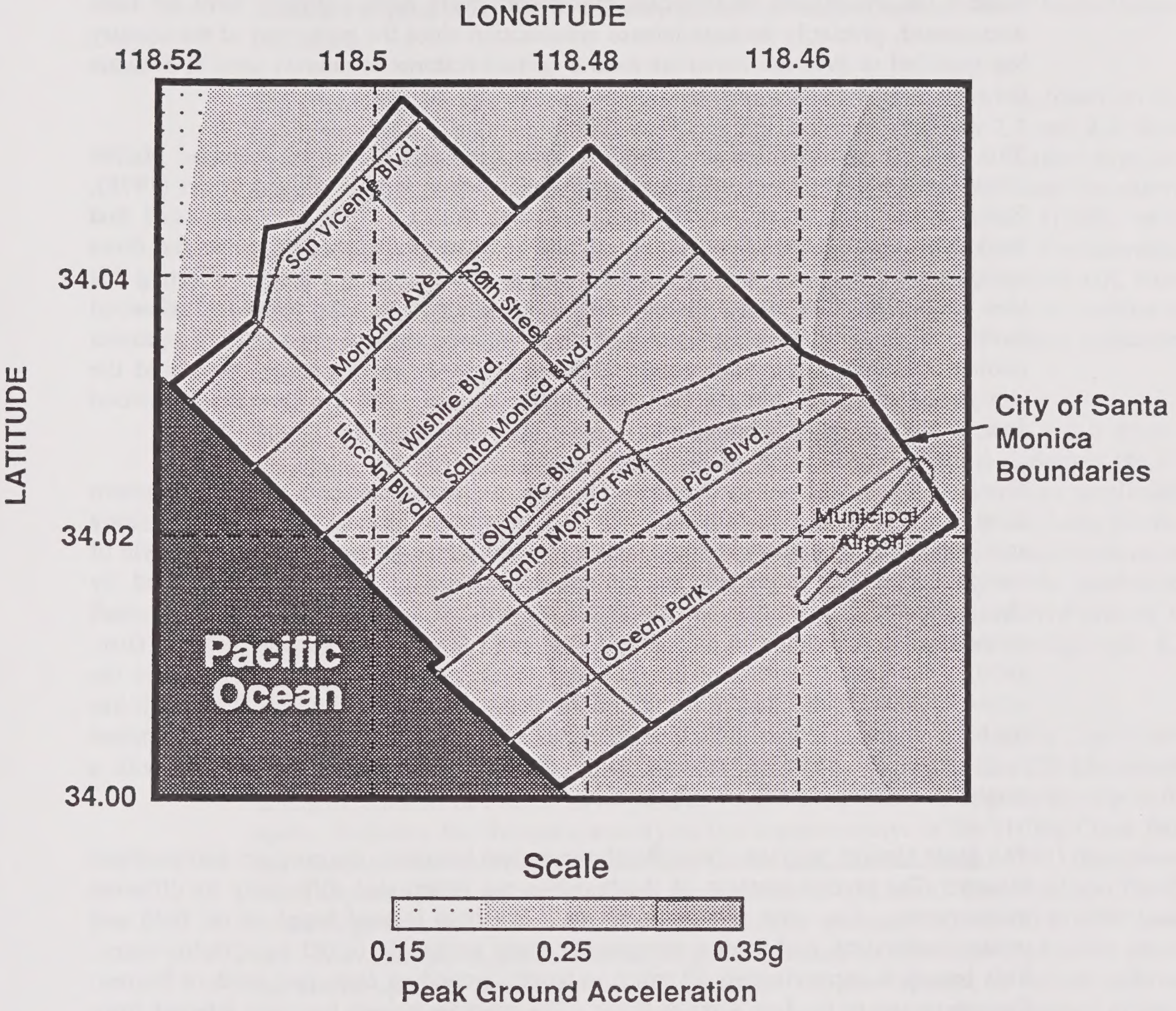

LONGITUDE
118.52
118.5
118.48
118.46
LATITUDE
34.04
34.02
34.00
San Vicente Blvd.
Montana Ave.
28th Street
Wilshire Blvd.
Santa Monica Blvd.
Lincoln Blvd.
Olympic Blvd.
Santa Monica Fwy.
Pico Blvd.
Municipal Airport
Ocean Park
Pacific Ocean
City of Santa Monica Boundaries
Scale
VIII
IX

Modified Mercalli Intensity Values shown in half-unit increments

Contour map of the Modified Mercalli Intensity values expected in Santa Monica from an earthquake of Magnitude 6.8 on the north branch of the Newport-Inglewood fault. Half intensity units represent the upper half unit of each intensity value. The boundaries between each unit represent a smooth variation in intensity, and should not be taken to be as sharply as herein defined.

Figure 1.6

Peak Horizontal Ground Accelerations for a Magnitude 6.8 Earthquake on the North Branch of the Newport-Inglewood Fault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Santa Monica Fwy.
Pico Blvd.
Ocean Park
Municipal Airport
Pacific Ocean
City of Santa Monica Boundaries
Scale
0.15
0.25
0.35g
Peak Ground Acceleration

Contour map of the peak ground acceleration values (g) expected in Santa Monica from an earthquake of Magnitude 6.8 on the north branch of the Newport-Inglewood fault.

Hollywood-Santa Monica-Malibu Coast Fault System

The Hollywood-Santa Monica-Malibu Coast fault system consists of a series of north-dipping high-angle reverse faults trending northeasterly, forming part of the southern boundary of the Transverse Ranges Province of southern California. This fault system extends offshore to include the Santa Rosa Island fault, the Santa Cruz Island fault, and the Anacapa fault. Some of the onshore fault segments have been determined to have late Pleistocene or Holocene movement; many more segments have not been documented, primarily because intense urbanization since the early part of the century has modified or even destroyed the natural surface features commonly used to evaluate the recency of activity of a fault.

This fault system has been interpreted to have been part of the much longer Malibu Coast-Santa Monica-Raymond-Cucamonga fault system, but Crook and others (1978), Crook (1983), Chapman and Chase (1979) and Weber (1980) have suggested that individual segments of this fault system should be treated independently, given that these fault segments appear to respond discretely to the complex tectonic stresses affecting this area of southern California. Recent studies also indicate that the Newport-Inglewood fault zone separates the Hollywood-Santa Monica fault zone into two distinct segments (Dolan and Sieh, 1991). Seismic analyses performed for this study considered the Hollywood and Santa Monica faults as separate entities, with the Newport-Inglewood fault acting as a segment boundary.

The Hollywood fault has been mapped as a narrow strand trending along the southern front of the Santa Monica Mountains for an approximate distance of 10.5 miles. Ziony and Yerkes (1985) characterize the fault as being reverse or reverse-oblique in style of motion. Holocene movement on the eastern portion of the fault is suggested by physiographic features that include linear scarps and inclined spurs, and by small earthquakes associated with this end of the fault (Ziony and Yerkes, 1985; Weber, 1980). The eastern portion of the fault also trends parallel to and is very near to the active Raymond fault. Recent activity on the western portion of the Hollywood fault has not been reported. An earthquake of magnitude 6.4 on the Hollywood fault is estimated to generate peak horizontal ground accelerations of about 0.43 g in the City, with a maximum shaking duration of 18 seconds.

The Santa Monica fault was generally shown as two branches, the northern and southern branch. The precise location of the branches are interpreted differently by different investigators. The north branch of the fault has been located based on oil field and ground water data, and from a topographic scarp noticeable in old topographic maps. This branch is approximately 25 miles in length, extending from just north of Potrero Canyon to east of the Los Angeles River. The southern branch has been inferred from oil well data in the Sawtelle Oil Field, and by a ground water barrier within Pleistocene sediments north of the Palisades Park (Poland, 1959). Both fault branches extend through portions of the City of Santa Monica (see Plate 1).

A new location for the Santa Monica fault, that falls between the north and south branches, has been mapped using primarily geomorphic data. Recent work by investigators at the California Institute of Technology in Pasadena (Dolan and Sieh, 1991), suggests that the active trace of the Santa Monica fault forms a series of left-stepping en echelon scarps 1.8 to 2.5 miles to the south of the south front of the Santa Monica mountains, within the City of Santa Monica. The fault scarps, which are formed by the intersection of the fault and the earth's surface, are shown on Plate 1. These are mapped within predominantly residential neighborhoods north of Santa Monica Boulevard.

The Santa Monica fault earthquake scenario prepared for this report is based on the occurrence of a magnitude 6.7 on the Santa Monica fault. Figures 2.7 and 2.8 show two-dimensional, contour representations of the Modified Mercalli intensities expected to be generated in the City of Santa Monica by this event. The seismic intensities shown on Figure 2.8 do not incorporate the 1.4 acceleration factor of Campbell (1988), while those on Figure 2.7 do. A comparison of the two figures shows that the 1.4 acceleration factor results in an increase in the expected intensities of approximately one unit, from level IX to level X, where shallow ground water has been reported, and an increase of one-half seismic intensity unit in the remaining areas of the City. The higher intensities also correspond to the areas where liquefaction may occur.

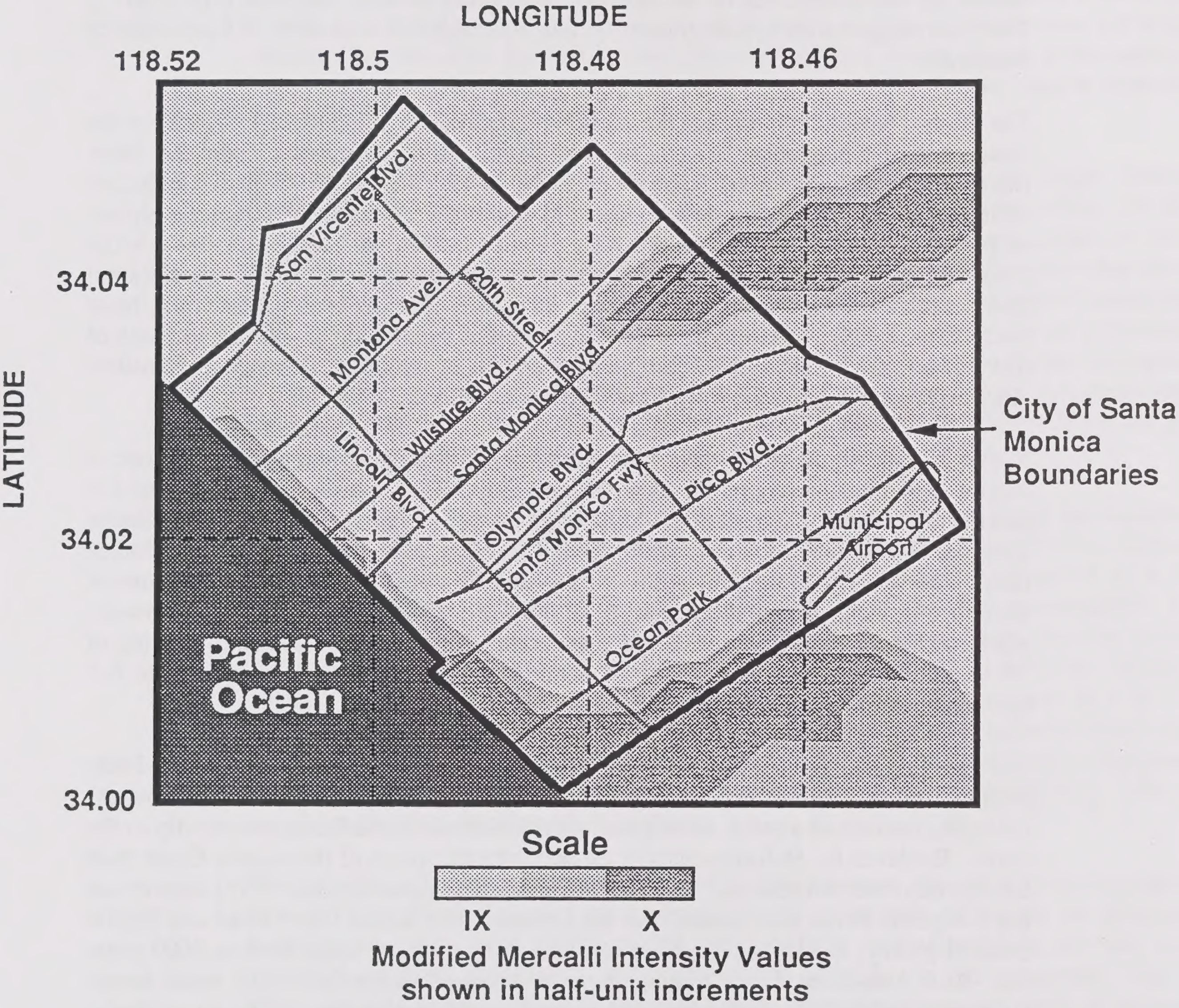
Figure 2.9 shows the peak horizontal ground accelerations expected to result from a magnitude 6.7 earthquake on the Santa Monica fault. The scenario incorporates the 1.4 acceleration factor of Campbell (1988) to represent the higher acceleration amplitudes observed to be generated during earthquakes by reverse faults, such as the Santa Monica fault. The worst-case scenario presented herein shows peak horizontal accelerations of about 0.64g along the southern margin of the City, and increasing to the northwest, where accelerations as high as 0.82g are predicted. An estimated duration of shaking of 21 seconds is predicted in the City of Santa Monica as a result of a magnitude 6.7 earthquake on the Santa Monica fault.

The Malibu Coast fault forms the western onshore terminus of the Malibu Coast-Santa Monica-Hollywood fault system. This fault, extending about 17 miles (27 kilometers) in length, consists of a series of subparallel reverse fault strands that generally dip to the north. Evidence for Holocene activity on two separate splays of the Malibu Coast fault has recently been documented. Converse Consultants (Rzonca et al., 1991) determined that a segment of the fault located near the intersection of Kanan Dume Road and Pacific Coast Highway, in Malibu, displaces colluvial soils estimated to be 5000 to 6000 years old. RSA Associates, Inc. (Drumm, in press) trenched a colluvium-filled swale across the central splay of the fault zone, and given the soil development of the ten colluvial deposits identified in the trench, estimated that the fault has a recurrence interval of about 4000 to 5000 years, with possibly two events having occurred during the Holocene.

Figure 1.7

Modified Mercalli Intensities for a Magnitude 6.7 Earthquake on the Santa Monica Fault

(peak ground accelerations are increased by a factor of 1.4 due to reverse faulting mechanism)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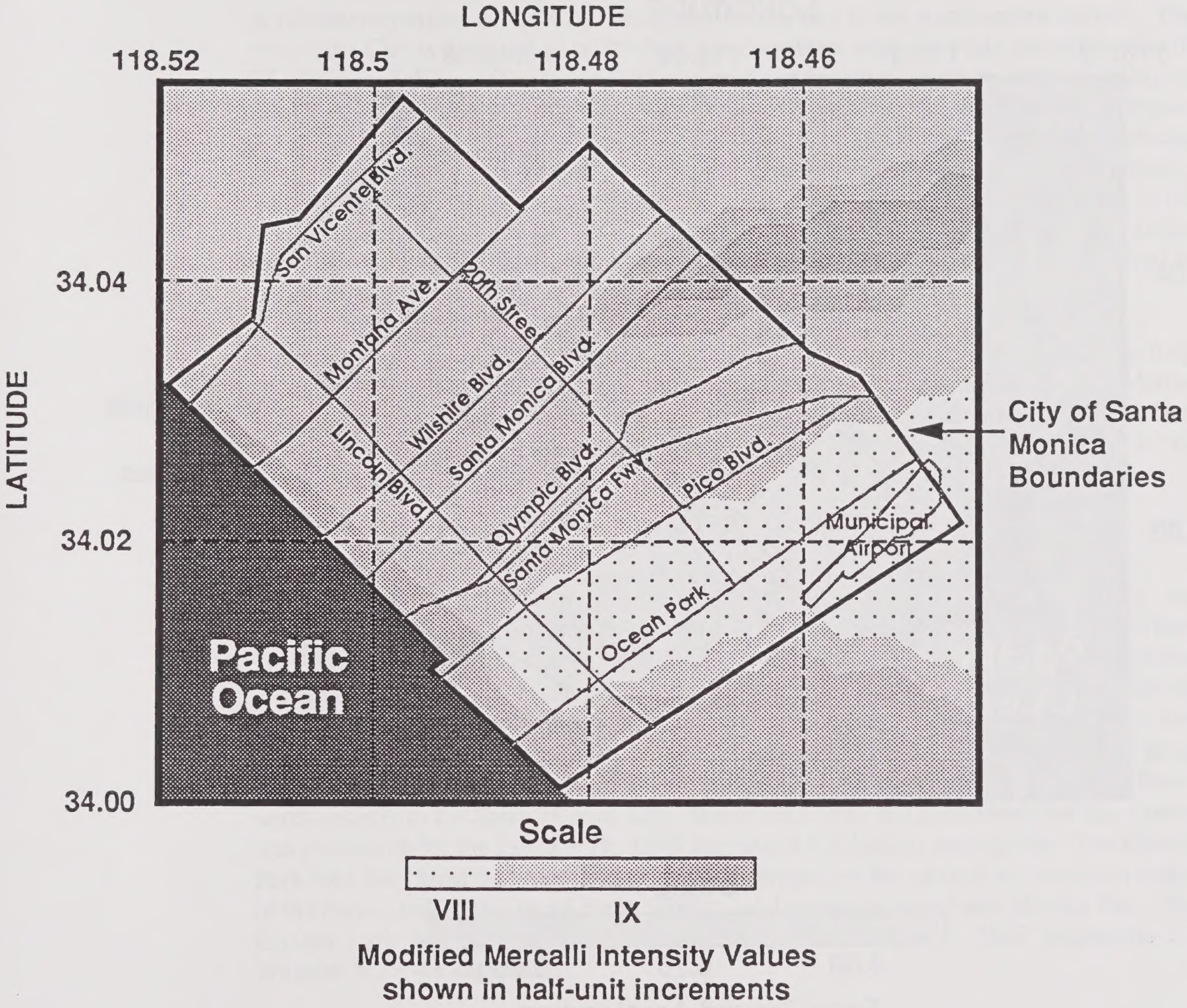
Ocean Park
Pacific Ocean
City of Santa Monica Boundaries
Scale
IX
X
Modified Mercalli Intensity Values shown in half-unit increments

Contour map of the Modified Mercalli Intensity values expected in Santa Monica from an earthquake of Magnitude 6.7 on the Santa Monica fault, using Campbell's (1988) acceleration factor of 1.4 for reverse faults. Half intensity units represent the upper half unit of each intensity value. The boundaries between each unit represent a smooth variation in intensity, and should not be taken to be as sharply as herein defined.

Figure 1.8

Modified Mercalli Intensities for a Magnitude 6.7 Earthquake on the Santa Monica Fault

(no increase in peak ground accelerations due to reverse faulting mechanism)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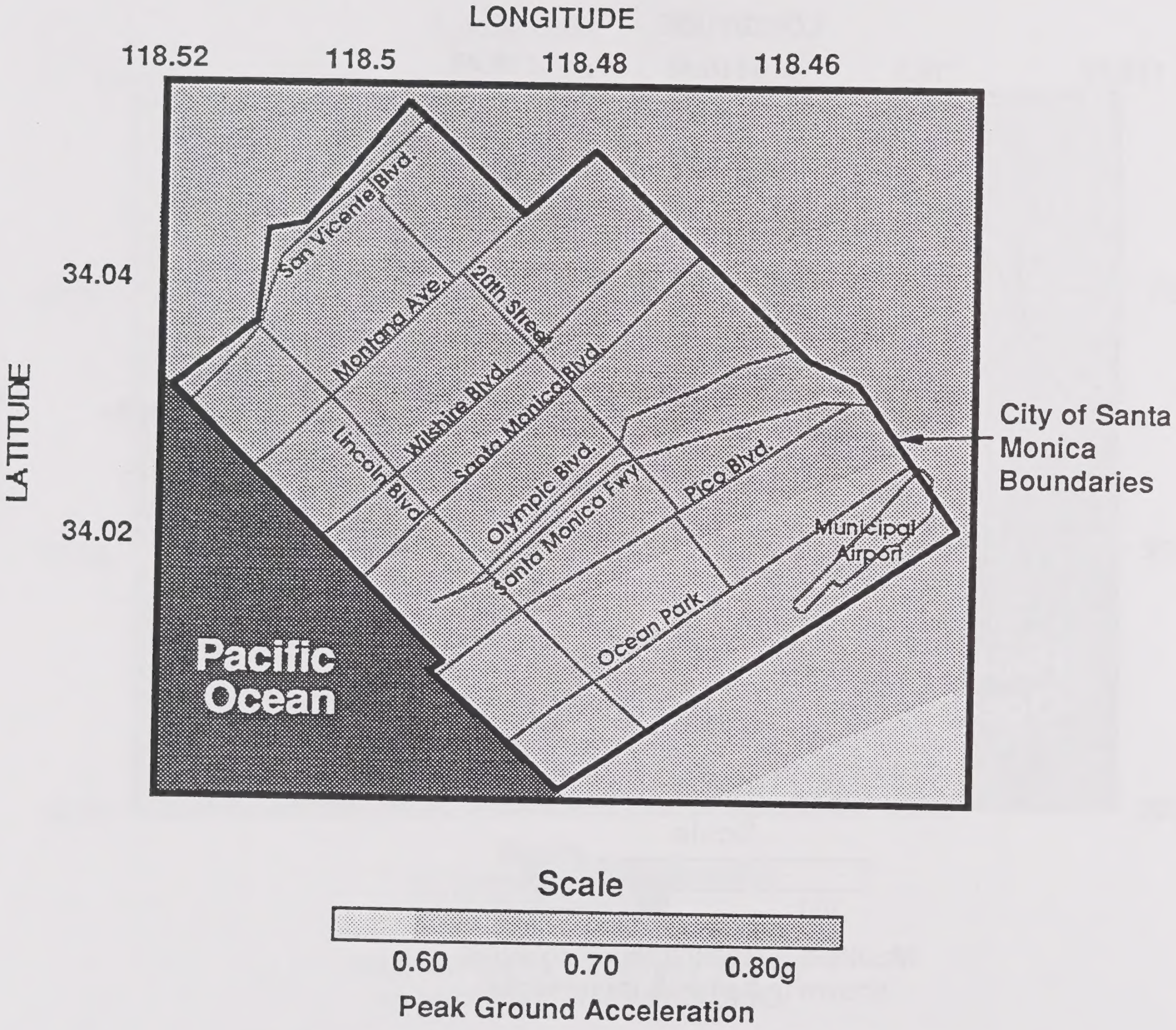
Pacific Ocean
City of Santa Monica Boundaries
Scale
VIII
IX
Modified Mercalli Intensity Values shown in half-unit increments

Contour map of the Modified Mercalli Intensity values expected in Santa Monica from an earthquake of Magnitude 6.7 on the Santa Monica Fault, without using Campbell's (1988) acceleration factor of 1.4 for reverse faults. Half intensity units represent the upper half unit of each intensity value. The boundaries between each unit represent a smooth variation in intensity, and should not be taken to be as sharply as herein defined.

Figure 1.9

Peak Horizontal Ground Accelerations for a Magnitude 6.7 Earthquake on the Santa Monica Fault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Pico Blvd.
Municipal Airport
Ocean Park
Pacific Ocean
City of Santa Monica Boundaries
Scale
0.60
0.70
0.80g
Peak Ground Acceleration

Contour map of the peak ground acceleration values (g) expected in Santa Monica from an earthquake of Magnitude 6.7 on the Santa Monica fault.

A magnitude 6.9 earthquake on the Malibu Coast fault was modeled to estimate the peak horizontal accelerations and seismic intensities that such an event would cause in the City of Santa Monica. Figures 1.10 and 1.11 show the seismic intensities, shown as contours on the City, expected to result in Santa Monica from an earthquake that ruptures the entire length of the Malibu Coast fault. The predicted seismic intensity values are similar to those predicted from a 6.7 event on the Santa Monica fault. The highest intensities, of level X, are expected to occur along the shallow ground water zones in the northeastern portion of the City, along the beach, and in the southeastern corner. The rest of the City is expected to suffer damages consistent with a seismic intensity value of IX (Figure 1.10). The same earthquake scenario was modeled without applying Campbell's (1988) acceleration coefficient. The results of this analysis, shown on Figure 2.11, indicate that not using the acceleration factor of 1.4 generally causes the predicted seismic intensities to drop a one-half intensity unit compared to the worst-case scenario, where Campbell's factor was considered. Liquefaction would be expected to occur in the shallow ground water areas of the City, given that a magnitude 6.9 event on the Malibu Coast is likely to generate seismic intensities above the VII level generally observed to result in liquefaction.

Figure 1.12 shows that peak horizontal ground accelerations ranging from 0.5g to 0.8g could occur in Santa Monica as a result of a magnitude 6.9 earthquake on the Malibu Coast fault. Ground motions in general decrease toward the south, away from the fault zone. This earthquake would cause about 24 seconds of strong ground shaking in the City.

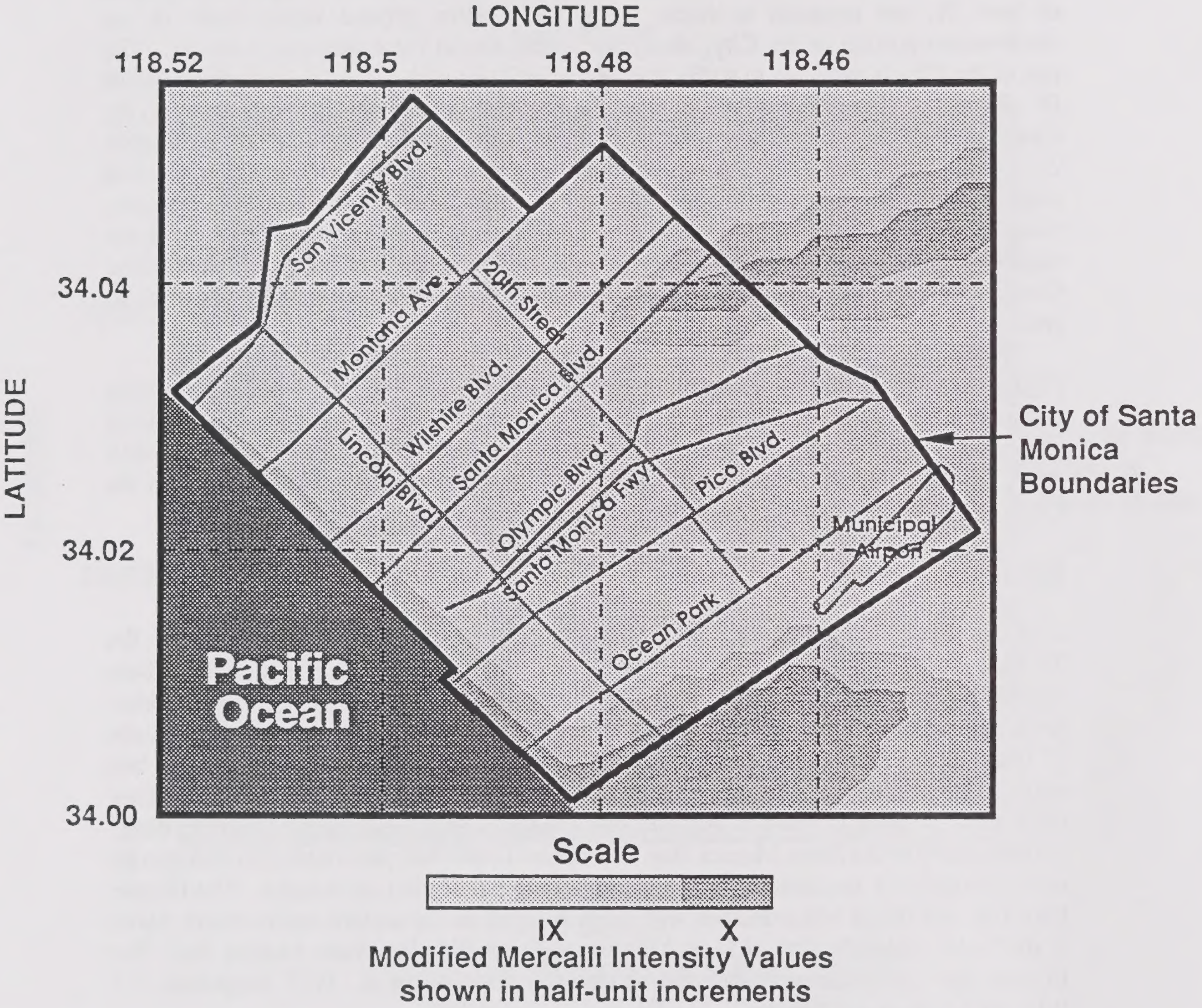
Buried Thrust Faults

Other seismic sources that may have an effect on the City include the Torrance-Wilmington and the Elysian Park fold and thrust belts (Figure 1.1). These "buried thrust faults" are named so because they are not exposed at the surface; the zones are broadly defined based on the analysis of seismic wave recordings of several hundreds of small earthquakes in the Los Angeles area, and are expressed at the surface by two major belts of folding. The Torrance-Wilmington fold and thrust belt is located along the southwest flank of the Los Angeles basin, extending from offshore Newport Beach northwesterly to the Santa Monica Bay. Hauksson (1990) has postulated that this system was the source for the January 19, 1989 magnitude 5.0 Malibu earthquake. The Elysian Park fold and thrust belt coincides with folds mapped on the eastern and northern flanks of the basin, under the City of Santa Monica, and extending into Santa Monica Bay. The Elysian Park belt was probably the source for the October 1, 1987 magnitude 5.9 Whittier Narrows earthquake.

Figure 1.10

Modified Mercalli Intensities for a Magnitude 6.9 Earthquake on the Malibu Coast Fault

(peak ground accelerations are increased by a factor of 1.4 due to reverse faulting mechanism)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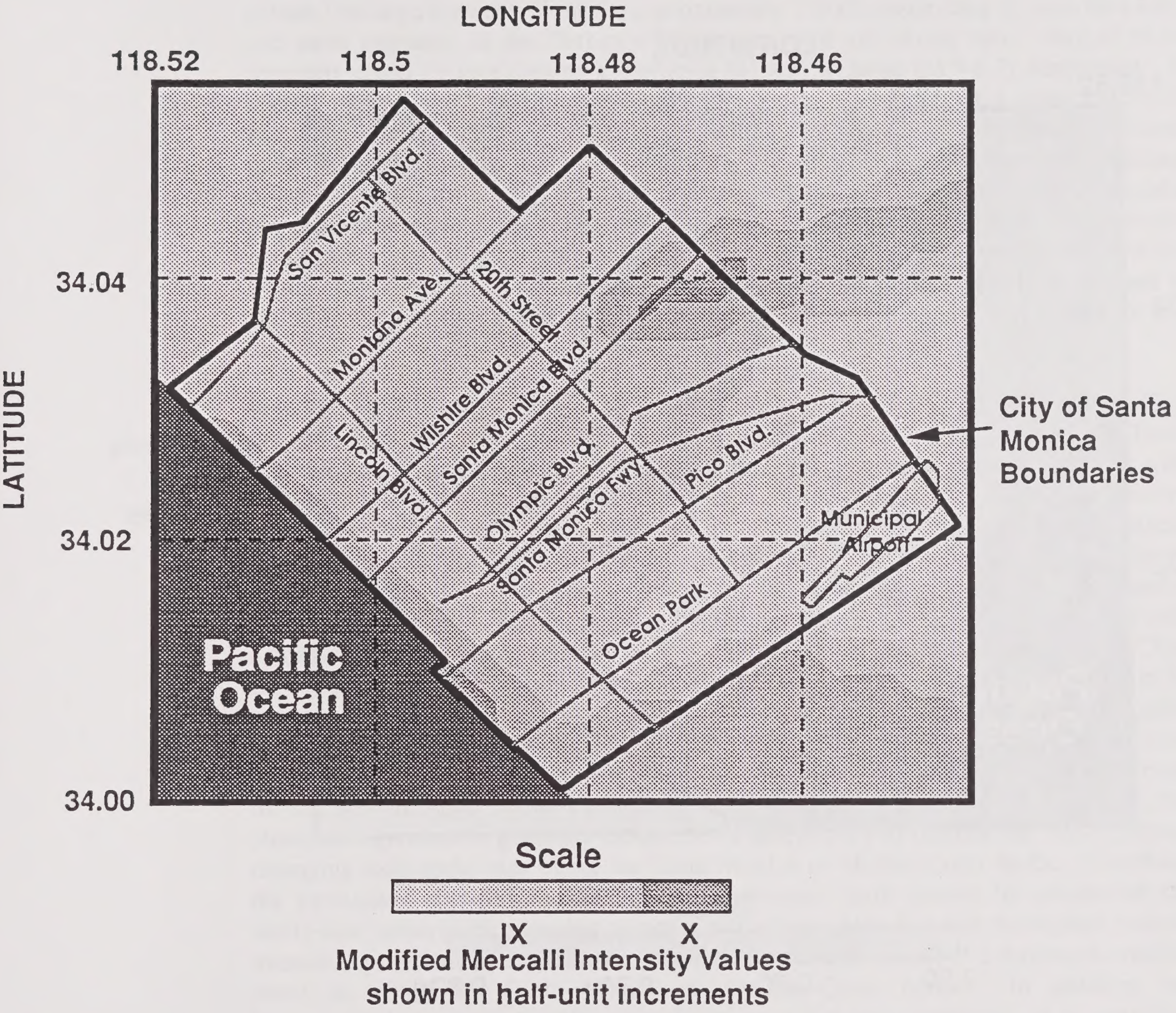
Municipal Airport
Ocean Park
Pacific Ocean
City of Santa Monica Boundaries
Scale
IX
X
Modified Mercalli Intensity Values shown in half-unit increments

Contour map of the Modified Mercalli Intensity values expected in Santa Monica from an earthquake of Magnitude 6.9 on the Malibu Coast fault, using Campbell's (1988) acceleration factor of 1.4 for reverse faults. Half intensity units represent the upper half unit of each intensity value. The boundaries between each unit represent a smooth variation in intensity, and should not be taken to be as sharply as herein defined.

Figure 1.11

Modified Mercalli Intensities for a Magnitude 6.9 Earthquake on the Malibu Coast Fault

(no increase in peak ground accelerations due to reverse faulting mechanism)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Santa Monica Fwy.
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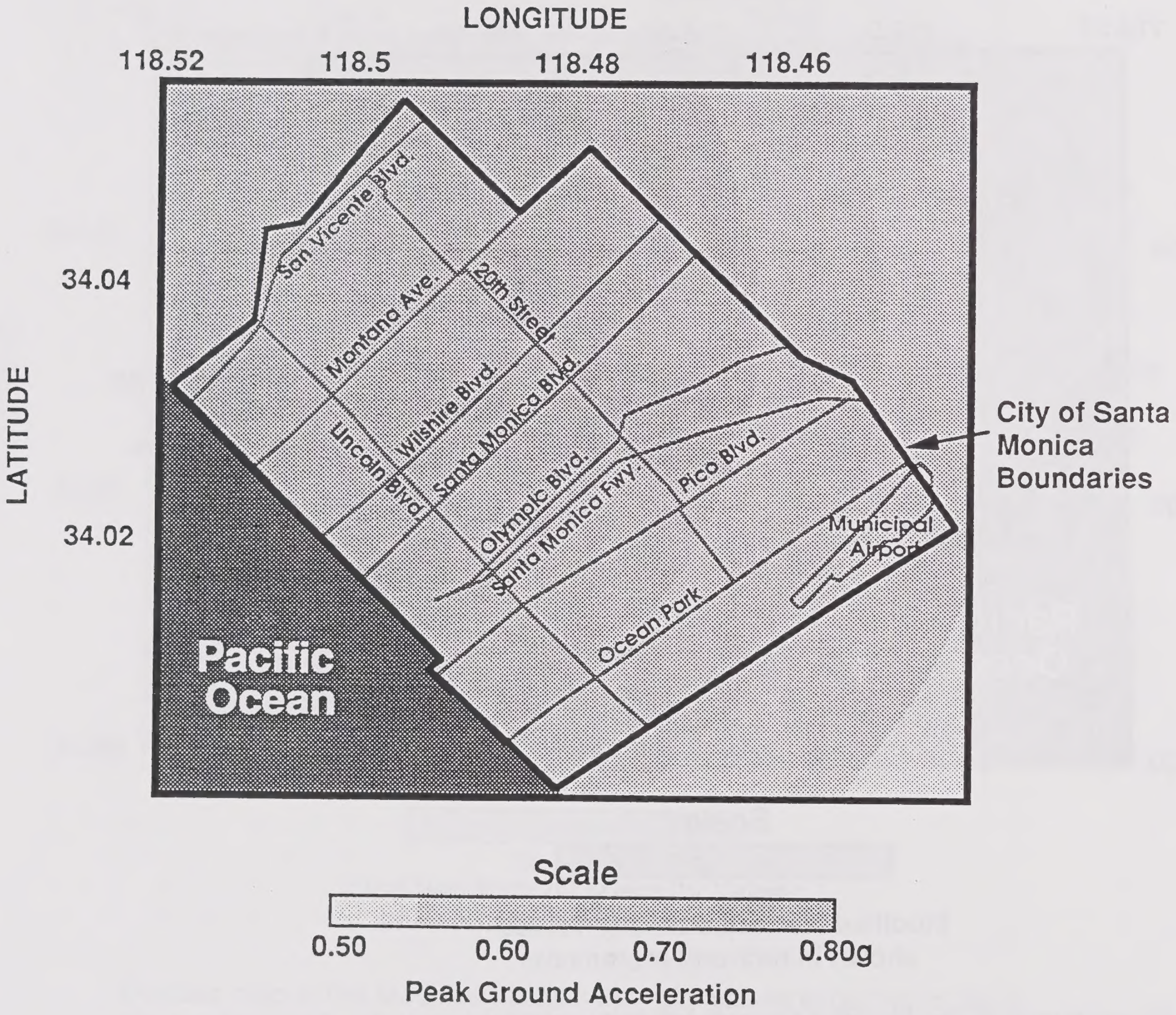
Ocean Park
Municipal Airport
Pacific Ocean
City of Santa Monica Boundaries
Scale
IX
X
Modified Mercalli Intensity Values shown in half-unit increments

Contour map of the Modified Mercalli Intensity values expected in Santa Monica from an earthquake of Magnitude 6.9 on the Malibu Coast fault, without using Campbell's (1988) acceleration factor of 1.4 for reverse faults. Half intensity units represent the upper half unit of each intensity value. The boundaries between each unit represent a smooth variation in intensity, and should not be taken to be as sharply as herein defined.

Figure 1.12

Peak Horizontal Ground Accelerations for a Magnitude 6.9 Earthquake on the Malibu Coast Fault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Lincoln Blvd.
Olympic Blvd.
Santa Monica Fwy.
Pico Blvd.
Ocean Park
Municipal Airport
Pacific Ocean
City of Santa Monica Boundaries
Scale
0.50
0.60
0.70
0.80g
Peak Ground Acceleration

Contour map of the peak ground acceleration values (g), expected in Santa Monica from an earthquake of Magnitude 6.9 on the Malibu Coast fault.

It is yet unknown whether each of these buried thrust systems consists of one continuous fault, or of many small abutting or overlapping faults (Hauksson, 1990). The Elysian Park fold and thrust belt is cross-cut by several strike slip faults, including the Whittier and the Newport-Inglewood faults. The Newport-Inglewood fault even appears to offset or segment the fold and thrust belt (Hauksson, 1990). Hauksson (1990) has identified at least five large segments along the approximately 100 kilometer-long Elysian Park belt, and three segments in the Torrance-Wilmington fold and thrust belt. Any of these segments could rupture causing a moderate ($M>5$) to large ($M>6.7$) earthquake. If several segments rupture simultaneously, Hauksson estimates that a great ($M>7.8$) earthquake could occur. Each segment may, in turn, be composed of one or several thrust faults. It is therefore possible that individual thrusts move independently, resulting in smaller magnitude earthquakes than if the segment moved as a whole. The earthquake potential of these fold and thrust belts is also difficult to evaluate because the seismic models commonly used to analyze the earthquake potential of faults require that the faults be defined as discrete planes. These thrust zones, therefore, need to be constrained in width. Given these uncertainties, the buried thrust fault systems were not modeled for this study.

Maximum credible earthquakes on other sources located within 63 miles of the City (including the Whittier, Palos Verdes, Sierra Madre, and San Fernando faults; see Table 1.3) could generate horizontal peak ground accelerations ranging from 0.01 to 0.3g, with an average expected duration of about 30 seconds. Table 1.3 shows the relative likelihood and impact of selected major earthquake sources on the City of Santa Monica. The anticipated "big one" on the San Andreas fault has the highest probability of occurring in the next 30 years. Several other faults, including the San Fernando, Elsinore and Whittier faults are more likely to rupture than the Newport-Inglewood, Santa Monica or Malibu Coast faults within a time span of concern to the City. However, the peak horizontal ground accelerations and seismic intensities expected to be generated in Santa Monica by such events are low enough that a closer earthquake source, likely to be more destructive in the City, should be emphasized for seismic hazard management and emergency planning purposes. Although recurrence intervals for the Newport-Inglewood, Santa Monica and Malibu Coast are tentative at best, the Newport-Inglewood is generally thought to be more likely to rupture and cause a strong damaging earthquake than either the Santa Monica or Malibu Coast faults. Therefore, the earthquake scenario on the Newport-Inglewood fault should be considered the worst-case scenario for planning purposes regardless of the fact that the highest seismic intensities predicted to occur in Santa Monica would be the result of a maximum credible event on either the Santa Monica or Malibu Coast faults. In addition, the Newport-Inglewood earthquake scenario presented herein, modeled as a near-field earthquake, best represents the worst-case damage anticipated to occur in Santa Monica from others more likely to move, but more distant earthquake sources, such as the Whittier fault.

Table 1.3

Relative Likelihood and Impact of Selected Major Earthquakes on the City of Santa Monica

A

Fault Name	Likelihood of Occurrence		Maximum Credible Earthquake
San Andreas (Mojave-San Bernardino Segment)	High	Most Likely	8.0
San Fernando	Moderate		6.5
San Andreas (Carrizo Segment)	Moderate		8.0
Elsinore	Moderate		7.1
Whittier	Moderate		7.3
Newport-Inglewood	Low		6.8
Offshore Newport-Inglewood	Low		6.8
San Gabriel	Low		6.7
Sierra Madre	Low		6.5
Hollywood	Very Low		6.4
Palos Verdes	Very Low		7.0
Malibu Coast	Very Low		6.9
Santa Monica	Very Low	Least Likely	6.7

B

Fault Name	MM Intensity in Santa Monica		Maximum Credible Earthquake
Santa Monica	IX-X	Most Severe	6.7
Malibu Coast	IX-X		6.9
Hollywood	IX		6.4
Newport-Inglewood	VIII-IX		6.8
Palos Verdes	VIII-IX		7.0
San Fernando	VII		6.5
Sierra Madre	VII		6.5
Whittier	VII		7.3
San Gabriel	VI-VII		6.7
San Andreas (Mojave-San Bernardino Segment)	VI-VII		8.0
San Andreas (Carrizo Segment)	VI		8.0
Offshore Newport-Inglewood	V-VI		6.8
Elsinore	V-VI	Least Severe	7.1

A) The maximum credible earthquake is the largest earthquake a fault is thought capable of generating. The likelihood of such an earthquake occurring within the next 100 years has been ranked as high, moderate, low or very low as follows: high - greater than 50% chance that such an earthquake will occur, moderate - 10 to 50%, low - 5 to 10%, very low - less than 5%.

B) The same faults are ranked according to their potential impact on the City of Santa Monica based on the Modified Mercalli intensity values that the maximum credible earthquakes are estimated capable of generating in the City.

1.1.2 Conclusions

- The Newport-Inglewood fault is assumed to be the most probable earthquake scenario for Santa Monica, posing the greatest threat to public safety and economic welfare, because this fault is capable of generating stronger ground motions in the City than the more distant San Andreas fault and is very seismically active.

- An earthquake of magnitude 6.8 on the north branch of the Newport-Inglewood fault will result in peak horizontal ground accelerations in the City of about 0.35 g, with Modified Mercalli intensities in Santa Monica ranging from levels VII to IX.

- The worst-case scenario is an earthquake of magnitude 6.7 on the Santa Monica fault would result in extensive damage to buildings and infrastructure, with Modified Mercalli intensities in Santa Monica as high as X. Peak horizontal ground accelerations estimated for the City range from 0.6g to 0.8g, with the stronger ground motions occurring in the northern industrial corridor of the City.

- In general, the highest Modified Mercalli intensities are expected to occur in areas where ground water occurs within 30 feet of the surface. These areas include the northern industrial corridor, and Marine Park area.

1.2 FAULT RUPTURE HAZARD

An analysis of fault rupture hazard for a particular fault requires that the subject fault be located exactly, and that its potential for fault rupture be known, if only approximately. The historical record (which in southern California extends back to 1769, when the first Spanish explorers reached the area), is too short a time period to characterize the earthquake recurrence of most faults. Geologists use repeatedly offset stratigraphic or physiographic features along a fault to reconstruct the earthquake history of the fault. Approximate recurrence intervals for major earthquakes on that particular fault can often be obtained from the analysis of field data. These recurrence intervals are then used in engineering design and planning decisions. Unfortunately, these kinds of data are available for only a few faults in southern California; the Santa Monica fault is not one of them. However, ongoing and future studies may produce reliable recurrence data within the next few years.

The analysis of fault rupture potential also assumes that a fault will slip along the same or nearly the same surface on which the fault last slipped. This assumption is generally true, based on observations from past surface-rupture events that show most ground ruptures do follow closely pre-existing fault traces. However, during an earthquake some sections of a fault may rupture the surface, while others may not. In conducting a fault-rupture hazard analysis the worst-case scenario is assumed, that is, that during a moderate to major earthquake the subject fault will rupture the surface in the area of study, in this case, the City of Santa Monica.

Surface rupture occurs when part of the stress released during an earthquake ruptures the fault plane at the earth's surface. In general terms, if the displacement is more than a few inches, structures that straddle the fault trace will be damaged or destroyed, since it is very costly to design structures to withstand large vertical or horizontal displacements. Other ground deformation phenomena associated with a seismic event include offset of the land surface, local tilting and warping of the ground near the fault, and uplift or subsidence of adjoining areas (Ziony and Yerkes, 1985). Damage due to fault rupture is catastrophic; however, not all surface displacements along faults need to occur suddenly and as a direct result of an earthquake. Fault creep, a slow differential movement or slip, can occur as a result of tectonic processes, or as a result of human activities, primarily the withdrawal of oil, gas or water from within the earth's crust (Ziony and Yerkes, 1985).

To mitigate the seismic hazard of fault rupture, the State of California enacted the Alquist-Priolo Special Studies Zone (APSSZ) Act of 1972 (Hart, 1990). In the State, the risk of fault rupture is weighted using the age of last proven faulting as a measure of whether the fault is likely to rupture again. Faults that can be proven by direct geologic observations to have moved in the last 11,000 years are assumed capable of rupturing the surface. The APSSZ Act focuses on active faults, as defined according to criteria developed by the California Division of Mines and Geology (CDMG). To implement the Act and designate a fault as active, the CDMG requires that Holocene-age (0 to 11,000 years old) sediments be proven or be suspected of having being displaced by the fault. Youthful geomorphology and structural distortion of near-surface Holocene deposits are also considered strong evidence of recency of activity. Under the provisions of the APSSZ Act, cities and counties where Special Studies Zones have been designated "must withhold development permits for sites within the zones until geologic investigations demonstrate that the sites are not threatened by surface displacement from future faulting." If a fault is proven to have moved within the last 11,000 years, structures intended for human occupation are not permitted to straddle the fault trace, and in some cases, not permitted to be built within 50 feet of the fault.

Faults with ambiguous evidence of activity may never be designated as APSSZ. However, new geologic and seismic data are continually reviewed by the CDMG in order to revise the Special Studies Zones, and to delineate additional zones. Given the large number of potentially active faults in the State, faults to be zoned need to meet the criteria of "sufficiently active" and "well defined." A fault is considered "sufficiently active" if there is "evidence of Holocene surface displacement along one or more of its segments or branches. Holocene surface displacement may be directly observable or inferred," and the evidence of displacement need not be present along the whole length of the fault to qualify the fault for zoning. A fault is considered well defined if "its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. The fault may be identified by direct observation or by indirect methods...". Determining whether a fault meets these criteria, however, is to a certain extent a matter of judgment. Interpreting the risk associated with a fault can often be compounded by the fact that geologic relationships used to evaluate Holocene faulting can be obscured by the accumulation of urban development, stream deposits, erosion, and landsliding.

1.2.1 Hazard Analysis

No Special Studies Zones have been designated by the California Division of Mines and Geology within the City of Santa Monica. The Santa Monica fault is considered potentially active, and does not meet the "sufficiently active" and "well-defined" criteria required for the fault to be zoned. Age and evidence of latest surface faulting of the Santa Monica fault is late Quaternary (last 750,000 years), based on offset stratigraphy, fault produced physiographic features, and ground water impediment within late Quaternary alluvial deposits (Ziony and Yerkes, 1985).

Recent and ongoing studies (Dolan and Sieh, 1991), however, may provide the additional data to meet the APSSZ criteria outlined above. In addition to the geomorphic fault scarps mapped by the Caltech researchers, two branches of the Santa Monica fault have been projected through City limits. The exact location of sections these branches are still questionable. The fault locations, as shown on Plate 1, represent a compilation of the best information available to date. "Well-located" fault segments are shown with a solid line on Plate 1; "moderately well-located" segments are shown with a dashed line, and "poorly located" segments are shown with a dotted and queried line. The three degrees of certainty as to the location of the fault are also shown; a narrow zone shows the area where the fault is well located, a wider zone where it is moderately well located, and the widest zone where the fault is poorly located. Proposed trenching studies of scarps associated with the Santa Monica fault may constrain further the location the Santa Monica fault (Dolan and Sieh, 1991).

The water barrier presumed to be caused by the south branch of the Santa Monica fault has been located in the following areas:

1) Near the intersection of Cloverfield and Olympic Boulevards in Santa Monica, where a fault-induced ground water depth differential of 70 feet has been documented. LeRoy Crandall and Associates (1986a, 1987) determined, as part of a geotechnical investigation for the proposed "Water Garden" project, that ground water depths north of the fault zone range from 40 to 50 feet below the ground surface, while ground water south of the fault zone is up to 120 feet deep. Dames and Moore (1985) conducted a geophysical survey for the same site, including natural gamma ray logs and two seismic refraction lines. Their survey indicated the presence of an east-west trending zone in the vicinity of the ground water barrier where a stratigraphic discontinuity was noted, and inferred to represent a fault contact. The south branch of the Santa Monica fault at this location, as determined from these studies, is about 700 feet north of the fault trace shown in the 1975 Seismic Safety Element (Envicom, 1975).

2) Between the easternmost segment of Olympic Boulevard in Santa Monica and the intersection of Bundy Drive and Olympic Boulevard in the City of Los Angeles, where ground water levels also appear to be affected by the inferred fault zone. Data supplied by the City of Santa Monica Water Division (personal

communication, 1991) show ground water to be about 120 feet below the ground surface along the easternmost segment of Olympic Boulevard, while ground water data obtained by Leighton and Associates, Inc. (1987) indicate water depths of about 40 feet at the intersection of Bundy Drive and Olympic Boulevard. Based on these data, the south branch of the Santa Monica fault has been "moderately well located" in this area.

3) From the intersection of Cloverfield and Colorado Boulevards to Wilshire Boulevard in Santa Monica, the fault has been "moderately well located". Ground water data obtained from Bailey (1968), City of Santa Monica Water Division (personal communication, 1991), LeRoy Crandall and Associates (1978, 1989b), Hill (personal communication, 1991), Los Angeles County (1990), Mendenhall (1950), and Poland and others (1959), indicate that the ground water barrier presumed to be associated with the south branch of the Santa Monica fault extends west-southwestwards to the intersection of Wilshire Boulevard and Sixteenth Street. Whether the ground water barrier presumed to be caused by the south branch of the Santa Monica fault extends further west is currently unknown. In Plate 1 the fault location has been queried past Wilshire Boulevard, and projected westward along the same trend to the Pacific Ocean.

The north branch of the Santa Monica fault, which has also been called the Potrero Canyon fault and the south branch of the Hollywood fault, has been "moderately well located" based on topographic evidence (Hill, 1979; personal communication, 1991), trenching studies (Crook, 1983), ground water data, and by projecting eastward the faults mapped in Potrero Canyon (Hill, 1979). A scarp-like feature has been described extending from between Stanford Street and Washington Avenue on the west, and Selby Avenue and Santa Monica Avenue on the east (Crook, 1983). Crook (1983) excavated several trenches in the U.S. Veterans Administration and University High School properties; the trenches were located to intersect this scarp. Features suggestive of faulting were observed in some of the trenches excavated, but whether or not the Santa Monica fault was exposed is inconclusive. The north branch has been "well located" near the corner of Wilshire Boulevard and Bundy Drive, in Los Angeles, where a ground water barrier has been reported to occur (Crook, 1983). Ground water levels in the northwest corner of the intersection are about 55 feet higher than in the southwest corner of the intersection, where ground water was encountered at about 70 feet below the ground surface.

The Santa Monica fault has not been clearly located, and has not been proven to displace Holocene sediments. The fault is, therefore, considered potentially active. However, several investigators have suggested that the fault is active. Trenching studies (Crook, 1983) have been inconclusive as to recency of activity of this strand, and the C.D.M.G. (1979) determined that Holocene movement on this fault could not be precluded. Some investigators suggest that the fault is active by association; the Santa Monica fault may be an extension of the active Malibu Coast fault to the west, or an extension of the active Hollywood fault to the east. Dolan and Sieh (1991) designate the Santa Monica fault as active, based on the youthful-looking scarps that occur along the trace of the fault. Their inferred fault locations do not occur at either the North or South branches, and furthermore, they have reported no geomorphic evidence for North or South faults. Finally, small earthquakes have been resolved geometrically to coincide closely with the fault's eastern end (Ziony and Yerkes, 1985).

1.2.2 Conclusions

- No Alquist-Priolo Special Studies Zones have been designated within the City limits of Santa Monica.
- The Santa Monica fault should be considered as an active ground rupturing structure. However, given the ongoing research, this conclusion should be reviewed frequently as new research data becomes available. The City should consider following the guidelines established in the Alquist-Priolo Special Studies Zones act, or establish more restrictive guidelines, for proposed new development within any area designated as a Hazard Management Zone. Construction of new critical facilities within these zones should be discouraged.

1.3 LIQUEFACTION HAZARD

Sections of the City of Santa Monica are susceptible to liquefaction, a very destructive secondary effect of strong seismic shaking. Liquefaction occurs primarily in saturated, loose, fine to medium-grained soils in areas where the ground water table is 50 feet or less below the ground surface. When these sediments are shaken, such as during an earthquake, a sudden increase in pore water pressure causes the soils to lose strength and behave as a liquid. Excess water pressure is vented upward through fissures and soil cracks causing a water-soil slurry to bubble onto the ground surface. The resulting features are called sand boils, sand blows or "sand volcanoes". Liquefaction-related effects include loss of bearing strength, ground oscillations, lateral spreading, and flow failures of slumping (Yerkes, 1985).

Loss of bearing strength occurs when the soil densifies and settles as a result of the seismic vibrations and resultant extrusion of water-soil slurries. This in turn may cause structural foundations to fail, and retaining walls to overturn. Large structures, such as multistory buildings and freeway interchanges, may settle several feet below original grade, or overturn. Structures are also damaged when ground oscillations occur. In this case, liquefaction occurs at depth in nearly level terrain. Surficial soil blocks separate from each other and "oscillate" on the underlying liquefied material.

Lateral spreading occurs when liquefaction occurs at depth but the terrain is sloped 0.3 to three percent. Surficial blocks of sediment riding on the underlying liquefied material move downslope destroying foundations, bridge piers, and utility, flood control, and transportation lifelines (Youd, 1978).

Flow failure is the most catastrophic effect of liquefaction; it occurs on slopes steeper than three percent. As with lateral spreading, flows of liquefied soil, or blocks of soil riding on liquefied material move downslope causing distress in structures and damaging utility lines. Emergency response capability immediately following an earthquake can be seriously impaired if evacuation routes, and water distribution or gas lines are damaged by earthquake induced liquefaction.

Several procedures have been developed to identify areas prone to ground failure. All procedures require the following site-specific information: a) the distribution of surficial and subsurface sediments that are youthful, cohesionless, and granular, and b) the location of shallow (50 feet or less) or perched ground water (water trapped in sediments at a higher elevation than that of the regional water table). Recently deposited sediments, particularly river-channel and flood-plain deposits, have been observed to be more susceptible to liquefaction than other deposits (Youd and Perkins, 1978). The distribution of particle sizes, whether the deposit consists of predominantly one grain size, or whether is a heterogeneous mix of sand, silt and clay, for example, also influences the liquefaction susceptibility of the sediment. Sand and silty sand deposits are most likely to liquefy. Bouldery and cobbly deposits, and deposits with fifteen percent or more clay are not known to liquefy (Tinsley and others, 1985). Loosely packed, unconsolidated deposits are also more likely to liquefy.

Site-specific geotechnical studies are the only practical and reliable way of determining the liquefaction potential of a site. Figure 1.13 shows a generalized geotechnical model used to investigate the liquefaction susceptibility of alluvial sediments. There are several useful references available to manage liquefaction hazards, including those by the Committee on Earthquake Engineering (1985), Ishihara (1985), and Seed and others (1983). The complete references are presented in the Bibliography section of this report.

1.3.1 Hazard Analysis

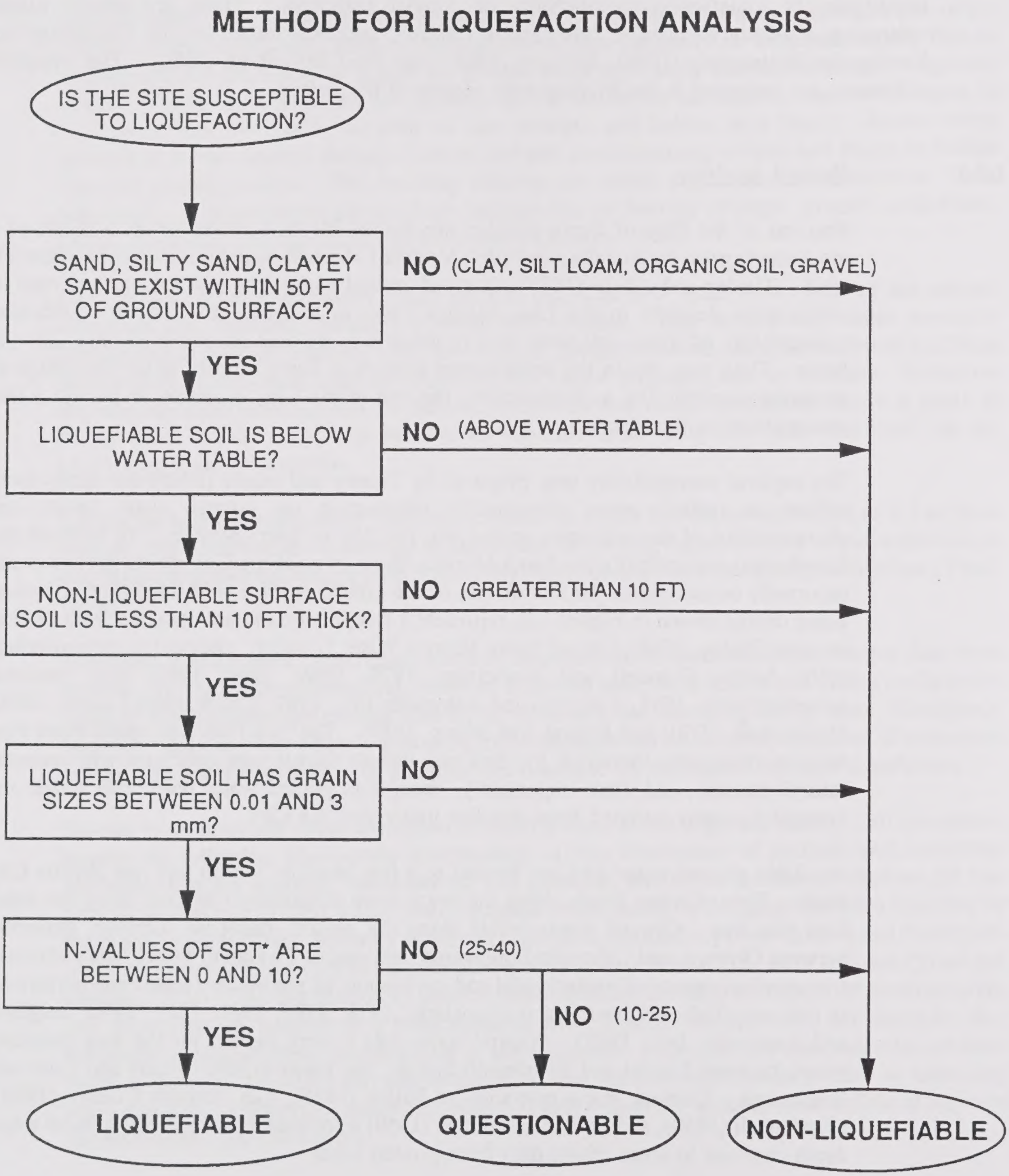
Portions of the City of Santa Monica are susceptible to liquefaction as a result of a moderate to great earthquake generating Modified Mercalli intensities above about the VII level. Tinsley and others (1985) reviewed ground water data and the age and type of sedimentary deposits in the Los Angeles Basin to evaluate the relative liquefaction susceptibility of these sediments and to develop a regional susceptibility map for the Basin. Their map shows the southeastern portion of Santa Monica as having a high to moderate susceptibility to liquefaction; the rest of the City is shown as having a low susceptibility to liquefaction.

The regional susceptibility map prepared by Tinsley and others (1985) has herein been refined to include more site-specific information on ground water levels and characteristics of the sediments underlying the City of Santa Monica. To evaluate the liquefaction susceptibility for Santa Monica, those areas of the City where ground water reportedly occurs within 50 feet or less of the ground surface were identified. Ground water depths shown in Figure 1.2 represent a compilation of data obtained from several sources (Bailey, 1968; City of Santa Monica Water Division, personal communication, 1991; LeRoy Crandall and Associates, 1978; 1986; 1989; 1990; Hill, personal communication, 1991, Leighton and Associates Inc., 1987; Los Angeles County, 1990; Mendenhall, 1950; and Poland and others, 1959). The data reviewed spans more than 40 years of records, therefore, the data may include fluctuations associated with seasonal rainfall patterns, and more importantly, changes in ground water levels that reflect the demand for water pumped from aquifers underlying the City.

Available ground water data are limited to a few locations within and just outside City limits. Ground water levels along the beach were estimated to be zero along the mean high tide line. Ground water levels along the central industrial corridor, generally between Olympic and Colorado Boulevards, and east of Twentieth Street, were obtained from various reports of geotechnical and environmental studies that have been performed in this area (LeRoy Crandall and Associates, 1978; 1986; 1987; 1989; 1990; Leighton and Associates, Inc., 1987). Ground water data is very limited for the area generally bound between Second and Fourteenth Streets, and between San Vicente and Colorado Boulevards. Contour maps prepared by Bailey (1968), Los Angeles County (1990), Mendenhall (1950), and Poland and others (1959) were used to estimate the ground water depth contours in areas where data from ground water

Figure 1.13

Generalized flow chart of a geotechnical method used to evaluate the liquefaction potential of a site.



METHOD FOR LIQUEFACTION ANALYSIS

IS THE SITE SUSCEPTIBLE TO LIQUEFACTION?
SAND, SILTY SAND, CLAYEY SAND EXIST WITHIN 50 FT OF GROUND SURFACE?
NO (CLAY, SILT LOAM, ORGANIC SOIL, GRAVEL)
YES
LIQUEFIABLE SOIL IS BELOW WATER TABLE?
NO (ABOVE WATER TABLE)
YES
NON-LIQUEFIABLE SURFACE SOIL IS LESS THAN 10 FT THICK?
NO (GREATER THAN 10 FT)
YES
LIQUEFIABLE SOIL HAS GRAIN SIZES BETWEEN 0.01 AND 3 mm?
NO
YES
N-VALUES OF SPT* ARE BETWEEN 0 AND 10?
NO (25-40)
NO (10-25)
YES
LIQUEFIABLE
QUESTIONABLE
NON-LIQUEFIABLE

* N is the number of blows required to advance a sampler a distance of one foot into the soil. In a Standard Penetration Test (SPT) the sample is driven using a 140-pound drop hammer.

wells or geotechnical borings were not available. Extrapolation between reported ground water data points, together with the above referenced ground water contour maps, were employed to obtain the ground water depth contours shown on Figure 2.2. These contours are generalized, and should not be used for site-specific studies.

Information on the surficial geology of the area was based primarily on Dibblee's (1991) geology map of the Beverly Hills and south one-half Van Nuys quadrangles. Four surficial sedimentary units that occur within City limits may be susceptible to liquefaction, given the right ground water conditions (Figure 1.2). These units are, from younger to older, beach sand deposits (geologic symbol Qs), alluvium (Qal), older alluvium (Qoa), and older marine deposits (Qom). All of these sediments are Quaternary in age, however, the alluvium and beach sand deposits are Holocene in age, and are, therefore, more likely to be unconsolidated, and to have a higher susceptibility to liquefaction.

The liquefaction susceptibility map shown in Plate 1 divides the City into four zones. High ground water levels (less than 50 feet below the ground surface) are reported along the beach, extending inland in the southwestern corner of the City to Marine Park, following the lowlands along Lincoln Boulevard, and in the northern industrial corridor of the City, where shallow ground water levels have been documented to exist behind a ground water barrier possibly associated with the south branch of the Santa Monica fault. Those areas underlain by beach sand or alluvium, and with ground water reportedly occurring within 30 feet of the surface, have been mapped as having a high susceptibility to liquefaction. This zone also includes the area along the beach where artesian conditions have been reported, and with ground water depths as shallow as 8 feet below the ground surface (LeRoy Crandall and Associates, 1989a). Areas underlain by Holocene sediments, and with water levels within 50 feet of the ground surface have been mapped as having a moderate susceptibility to liquefaction, while areas underlain by older alluvium or older marine deposits, and with water levels within 50 feet of the surface have been considered to have a low susceptibility to liquefaction. The remaining areas of the City are mapped as having a very low to no liquefaction susceptibility.

In addition to the geologic and hydrologic conditions included in the above discussion, Modified Mercalli intensities of VII and higher have been observed to be required for liquefaction to occur (Toppozada et al., 1988). The earthquake sources capable of generating these levels of shaking in Santa Monica, with the consequent potential of inducing liquefaction in the City, are presented in Table 1.4.

Table 1.4

Faults Capable of Generating Maximum Credible Earthquakes that can Cause Liquefaction in Santa Monica

Mcr*	Fault Name
6.7	Santa Monica
6.9	Malibu Coast
6.4	Hollywood
6.8	Newport-Inglewood
7.0	Palos Verdes
8.0	San Andreas (Mojave-San Bernardino segment)
8.0	San Andreas (Carrizo segment)
6.5	San Fernando
7.3	Whittier
6.7	San Gabriel

This analysis assumes that the fault ruptures at the point closest to the City of Santa Monica. The analysis is based on the relation between earthquake magnitude and maximum distance at which liquefaction has occurred in past earthquakes (from Tinsley et al., 1985).

* Maximum credible earthquake: The largest earthquake a fault is believed capable of generating.

Liquefaction susceptibility maps such as that shown in Plate 1 are general in scope. These maps should be used only as regional planning tools, rather than as substitutes for site-specific studies. Lateral variations in the physical properties, and therefore liquefaction susceptibility, of flood plain and other alluvial deposits cannot be represented adequately in these maps. Data on grain size distribution of the underlying sediments, coupled with standard penetration test readings (or similar techniques) that characterize the density or stiffness, and therefore, degree of consolidation of these deposits, are necessary to evaluate the liquefaction susceptibility of a site. The map shown on Plate 1 was prepared without the benefit of these data. The liquefaction vulnerability of a site can also fluctuate seasonally, or change through time, as a response to regional changes in the levels of shallow or perched ground water. Ground water levels in an area vary due to ground water management practices, and due to seasonal variations in precipitation and recharge patterns. In addition, localized perched ground water conditions, common in alluvial deposits, cannot be represented adequately.

1.3.2 Conclusions

- Areas having a high to moderate susceptibility to liquefaction have been identified in the northern industrial corridor of the City, along the beach, and in the south portion of the City extending to the Marine Park area.
- Ground water in these areas reportedly occurs within 30 to 50 feet from the ground surface. These areas are also underlain by youthful, Holocene to late Pleistocene alluvial and beach deposits.

1.4 VULNERABILITY OF SANTA MONICA TO SEISMIC HAZARDS

This section identifies and discusses the opportunities available for seismic upgrading of existing development and capital facilities, including potentially hazardous buildings, utilities, transportation infrastructure, and other critical facilities. Many of the issues and opportunities available to the City apply to new development, redevelopment and infilling; however, issues involving rehabilitation and strengthening of existing development are decidedly more complex given the economic and societal impacts inherent to these issues.

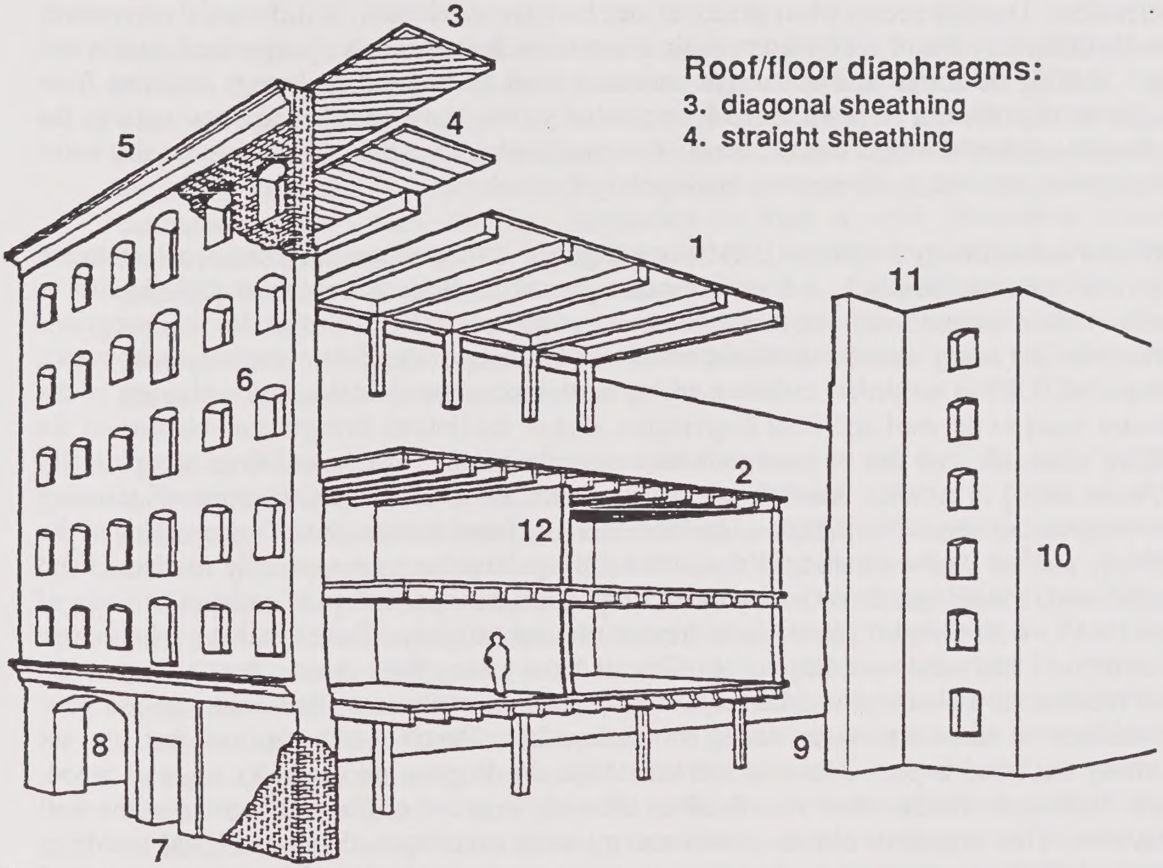
Prioritizing rehabilitation and strengthening projects requires that the City consider where its resources would be better spent to reduce earthquake hazards in the existing development, and how can the proposed mitigation programs be implemented so as not to cause undue hardship on the community. The first issue is intended to define the scope of the problem. Rehabilitation programs should target, on a priority basis, potentially hazardous buildings, critical facilities, high-risk lifeline utilities, and development located in areas of high seismic risk. The second issue can be best addressed by the City, keeping in mind the specific population make-up of Santa Monica. The Safety Element and Policies Report addresses further issues and opportunities aimed specifically at special population groups, including senior citizens, physically disabled persons, and non-English speaking groups.

The following discussion on the vulnerability of Santa Monica to seismic hazards assumes that most injuries and property damage associated with a major earthquake impacting the City will be caused by the damage and collapse of structures as a result of strong ground shaking. Two-thirds of the housing units in Santa Monica are multi-family structures, another one-fifth consists of single-family structures (1990 Census figures). More than fifty percent of the housing units in Santa Monica were built prior to 1960; about eighty percent were built prior to 1970. Almost four-fifths of Santa Monica residents rent the units where they live. Figures from the 1990 Census also show that, on average, housing costs and market rent rates in Santa Monica are much higher than those in Los Angeles County.

Potentially Hazardous Buildings and Structures: Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures. FEMA (1985) defines a hazardous building as "any inadequately earthquake resistant building, located in a seismically active area, that presents a potential for life loss or serious injury when a damaging earthquake occurs". Building codes have generally been made more stringent following a damaging earthquake, such as the 1933 Long Beach and the 1971 San Fernando earthquakes. However, a large percentage of structures in southern California were built prior to 1971, have not been upgraded to current building code standards, and can therefore be potentially hazardous during an earthquake.

Figure 1.14

Typical Unreinforced Masonry Construction



Roof/floor span systems:

1. wood post and beam (heavy timber)
2. wood post, beam, and joist (mill construction)

Roof/floor diaphragms:

3. diagonal sheathing
4. straight sheathing

Details:

5. typical unbraced parapet and cornice
6. flat arch window openings
7. typical penetrated facade of residential buildings
8. large openings of ground floor shops (soft-story)

Wall systems:

9. bearing wall - four to eight wythes of brick
10. typical long solid party wall
11. light/ventilation wells in residential building
12. non-structural wood stud partition walls

Unreinforced masonry buildings are known to perform poorly in earthquakes. (Figure from FEMA, 1988).
]

Damage to buildings is commonly classified as either structural or non-structural. Structural damage means the building's structural support has been damaged. Structural support includes any vertical and lateral force resisting systems, such as the building frames, walls, and columns. Non-structural damage does not affect the integrity of the structural support system. Examples of non-structural damage include broken windows, collapsed or rotated chimneys, and fallen ceilings. During an earthquake, buildings get thrown from side to side, and up and down. Heavier buildings are subjected to higher forces than lightweight buildings, given the same acceleration. Damage occurs when structural members are overloaded, or differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking durations tend to damage structures more. The level of damage resulting from a major earthquake can be predicted only in general terms, since no two buildings undergo the exact same motions during a seismic event. Past earthquakes have shown us, however, that some buildings are more likely to perform more poorly than others.

Unreinforced masonry buildings (URMs) (see Figure 1.14) have been receiving much attention as a result of State Bill 547, a State ordinance passed in 1986 that required jurisdictions to inventory their unreinforced masonry structures by January 1, 1990, and to develop programs to minimize the safety hazards associated with these buildings. Based on observations from past earthquakes, URMs are prone to failure during earthquakes due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, due to the limited strength and ductility of the building materials, and due to poor construction workmanship. These buildings are generally old, some dating to even the late 18th century, therefore, those URMs in California still standing have experienced several earthquakes, probably have suffered damage, including cracking of the masonry, and are thus weakened. Unless the buildings have been appropriately reinforced and strengthened, another earthquake may cause irreparable damage, and even collapse of some of these URMs, with the resultant threat to human life and property. Deterioration of the mortar (often of lime and sand with little or no cement, having very little shear strength) and of the wood framing as a result of weather exposure may also contribute to the weakening and poor performance of these structures during an earthquake. Parapets and cornices that are not positively anchored to the roofs may fall out. Wall diaphragms are generally made of wood. These diaphragms are therefore very flexible, allowing large out-of-plane deflections at the wall transverse. This large drift can cause the masonry walls to collapse. Some tall URM buildings have thin walls that may buckle out-of-plane under severe lateral loads. If the wall is a non-load bearing wall, it may fail; collapse of a load-bearing wall will result in partial or total collapse of the structure.

Although URMs have been assumed to be the most hazardous buildings in a community, the collapse of URM buildings during an earthquake, in general, may not pose as much a hazard to loss of life as the collapse of other types of structures. Several other building types are also known to perform poorly during moderate to strong earthquakes, although they have not been targeted for upgrading and strengthening. Of these, **soft-story** (see Figure 1.15) buildings (those with a story, generally the first floor, lacking adequate strength or toughness, due to few shear walls, i.e., buildings where the first floor is the garage) are of particular concern. The walls with large door openings common to garages have almost no resistance to lateral forces. If a second or more stories sit on top of the garage, the building may sustain significant amounts of damage, and even collapse during an earthquake. A soft-story building can also be one which has large window openings for display purposes on the first floor.

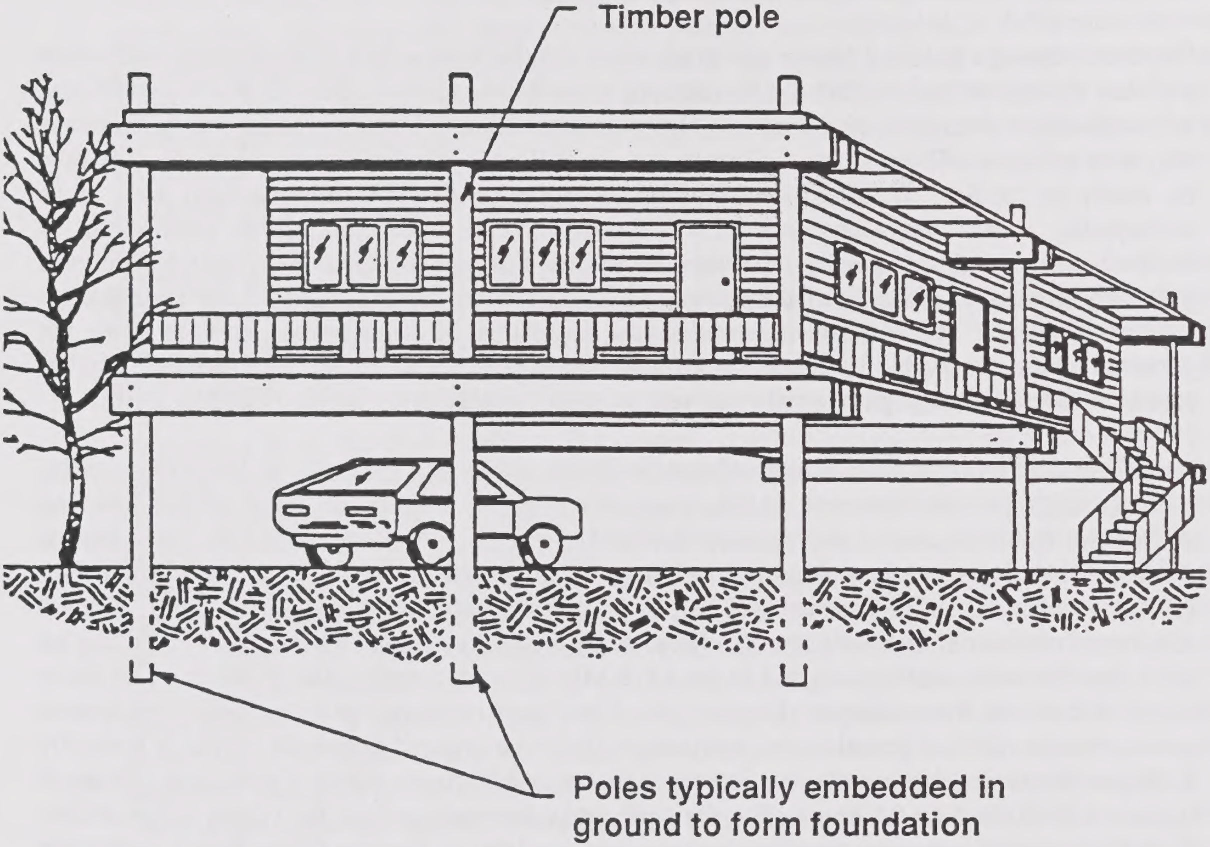
Some soft-story buildings have a timber pole construction. The poles are often subject to wood deterioration with exposure to the elements. This deterioration, if unchecked and allowed to occur, may also contribute to unsatisfactory seismic performance.

Structural damage to **wood frame** structures often results from a lack or inadequate connection between the superstructure and the foundation; these buildings may slide off their foundations, with consequent damage to plumbing and electrical connections. Unreinforced masonry chimneys may also collapse. These types of damage are generally not life threatening, although they may be costly to repair. Wood frame buildings with stud walls generally perform well in an earthquake, unless they have no foundation or have a weak foundation constructed of unreinforced masonry or poorly reinforced concrete. Damage to wood stud frame buildings is generally limited to cracking of the stucco, which in fact, dissipates much of the earthquake's induced energy. The collapse of wood frame structures, if it happens, generally does not generate heavy debris; but rather, the wood and plaster debris can be cut or broken into smaller pieces by hand-held equipment and removed by hand to reach any victims (FEMA, 1988).

Partial or total collapse of buildings where the floors, walls and roofs fail as large intact units, such as large **precast concrete** panels, cause the greatest concern in terms of life loss and difficulties in victim rescue and extrication (FEMA, 1988). Thousands of people have died as a result of collapse of these kinds of buildings during earthquakes, such as in Mexico City (1985), Armenia (1988), Nicaragua (1972), El Salvador (1986), and Philippines (1990). Several reinforced concrete frame buildings also failed at the Veterans Administration Hospital during the 1971 San Fernando earthquake, and in the 1978 Miyagiken-oki earthquake in Japan. The heavy debris that results from collapse of these types of buildings requires heavy mechanical equipment to remove the rubble. Location and extrication of victims trapped under the rubble is generally a dangerous process that requires equipment to tunnel and lift heavy debris Extrication of trapped victims within the first 24 hours after the earthquake becomes critical for victim survivability. In most instances, however, the planning resources available to procure the necessary equipment for victim rescue are ill-defined to non-existent. Buildings that are more likely to generate heavy debris in case of failure need to be identified, so that appropriate mitigation and planning procedures are defined prior to an earthquake.

Figure 1.15

Typical Timber Pole Frame Construction


Timber pole
Poles typically embedded in ground to form foundation

The wooden poles used in this type of building construction are prone to deterioration due to exposure to the elements. This deterioration can lead to poor seismic performance. Buildings of this type also have a soft-story that may provide inadequate resistance to the lateral forces commonly caused by earthquakes. (Figure from FEMA, 1988).

Precast concrete frame buildings vary in their performance during earthquakes, dependent in part on the strength and toughness of the details connecting the structural elements. If poorly designed connections between prefabricated elements fail, the damage and loss of life can be significant. Precast frames are often weakened due to a combination of the accumulated stresses that may result from shrinkage and creep, and due to stresses incurred during transportation. Vertical support may fail if the building was designed with an inadequate bearing area and/or with insufficient connections between floor elements and columns. Corrosion of the metal connectors between prefabricated elements may also occur weakening the structure. Multi-story concrete and reinforced masonry buildings with concrete floor slabs may collapse with the floor slabs falling, nearly intact, one on top of the other, becoming closely stacked ("pancake" style of failure). The floor slabs prevent access to, and extrication of victims. Given the large size and weight of these slabs, some weighing up to 250 tons, the slabs generally need to be cut into smaller segments prior to removal by heavy cranes. The cutting of these slabs is a time-consuming process that requires breaking the concrete and cutting the reinforcing steel.

Tilt-up buildings have concrete wall panels, often cast on the ground, or fabricated off-site and trucked in, that are tilted upward into their final position. Prior to 1973, these wall panels were generally not anchored adequately to the walls and roof and floor diaphragms. The weak connections and anchors have been observed to pull out of the walls during an earthquake, causing the floors or roofs to collapse. New tilt-up buildings are required to have positive wall-diaphragm connections; yet many pre-1973 vintage buildings of this type exist which have not been retrofitted to correct this wall anchor defect. Tilt up buildings may generate heavy debris if concrete wall panels fail.

Reinforced masonry buildings often perform well in moderate earthquakes if they are adequately reinforced and grouted, and if sufficient diaphragm anchorage exists. Poor construction workmanship, resulting in ungrouted and unreinforced walls may lead to failure of the building during a large earthquake. Insufficient reinforcement can also result in heavy damage to walls, while lack of positive connections of the floor and roof diaphragms can also result in structural damage.

Reinforced concrete frame buildings with or without reinforced infill walls display low ductility. Typical problems with this kind of building during an earthquake include shear failure if there are large tie spacings in columns, or if columns have insufficient shear strength, column failure if inadequate rebar splices are placed at the same location, shear failure of columns with insufficient tie anchorage, hinge deformation due to lack of continuous beam reinforcement, column failure due to inadequate reinforcing of beam-column joints, and non-structural damage due to the relatively low stiffness of the frame.

Multi-story steel buildings generally also have concrete floor slabs. However, these buildings are less likely to collapse than concrete structures. Common damage to these types of buildings is generally non-structural, including collapsed exterior curtain wall (cladding), and damage to interior partitions and equipment. Older, pre-1945 steel frame structures may have unreinforced masonry such as bricks, clay tiles and terra cotta tiles as cladding or infilling. Cladding in newer buildings may be glass, infill panels or pre-cast panels that may fail and generate a band of debris around the building exterior (with considerable threat to pedestrians in the streets below). Structural damage may occur if the structural members are subject to plastic deformation which can cause permanent displacements; if some walls fail while others remain intact, torsion or soft-story problems may result. Pounding with adjacent buildings can also occur.

Buildings are often, however, a combination of steel, concrete, reinforced masonry and wood, consisting of different structural systems on different floors or different sections of the building. Of these, those types considered to be potentially hazardous (and that have not been discussed above) include: concrete frame buildings without special reinforcing, precast concrete and precast-composite buildings, steel frame or concrete frame buildings with unreinforced masonry walls, reinforced concrete wall buildings with no special detailing or reinforcement, large capacity buildings with long-span roof structures (such as theaters and auditoriums), large unengineered wood-frame buildings, buildings with inadequately anchored exterior cladding and glazing, and buildings with poorly anchored parapets and appendages (FEMA, 1985). Additional types of potentially hazardous buildings may be identified in the future as a result of observations of damaged structures after an earthquake.

The configuration of the building, that is, its vertical and/or horizontal shape can also be an important factor in earthquake performance. Simple, regular and symmetric buildings in general perform better than non-symmetric buildings. Non-symmetric buildings tend to twist in addition to shake laterally, while wings on a building tend to act independently during an earthquake, resulting in differential movements, and cracking. The geometry of the lateral load resisting systems is another component of a building's configuration (for example buildings with one or two walls made mostly of glass, while the remaining walls are made of concrete or brick). Asymmetry in the placement of bracing systems that provide a building with earthquake resistance can result in twisting or differential motions, with resultant damage.

Site-related seismic hazards may include the potential for neighboring buildings to "pound" the structure, or for the neighboring buildings to collapse onto the adjacent building. Pounding occurs when there is little clearance between adjacent buildings, and the buildings "pound" against each other as they deflect during an earthquake. The effects of pounding can be specially damaging if the floors of the buildings impacting each other are at different elevations, so that, for example, the floor of one building hits a supporting column of the adjacent building. Damage to the column can result on partial or total collapse of the impacted building.

Critical Facilities: These are facilities and parts of a community's infrastructure that must remain operational after an earthquake, or facilities that pose unacceptable risks to public safety if severely damaged. Essential facilities are needed during an emergency, such as hospitals, fire and police stations, emergency operation centers and communication centers. High-risk facilities, if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include nuclear power plants, dams and flood control structures, freeway interchanges and bridges, industrial plants that use or store explosives, toxic materials or petroleum products.

High-occupancy facilities have the potential of resulting in a large number of casualties or crowd control problems. This category includes high-rise buildings, large assembly facilities, and large multifamily residential complexes. Dependent care facilities house populations with special evacuation considerations, such as preschools and schools, rehabilitation centers, prisons, group care homes, and nursing and convalescent homes. Economic facilities are those facilities which should remain operational to avoid severe economic impacts, such as banks, archiving and vital record keeping facilities, airports and ports, and large industrial and commercial centers.

It is essential that critical facilities designed for human occupancy have no structural weaknesses that can lead to collapse. The State of California has jurisdictional responsibility to ensure that public school buildings are adequately constructed to meet seismic design standards (Garrison Act, 1969). The responsibility for primary design and regulatory review for new hospital buildings also resides with the State as a result of the Hospital Act of 1972. The design and construction standards implemented as a result of this legislation are considerably more rigorous than those employed in the construction of older, pre-1972 hospitals. Many older hospitals may also have nonstructural and fire safety provisions that do not meet current code standards. State law requires that general acute care hospitals be upgraded to current earthquake design standards if undergoing voluntary rehabilitation. The Federal Emergency Management Agency (FEMA, 1988) has suggested the following seismic performance goals for health care facilities:

- The damage to the facilities should be limited to what might be reasonably expected after a destructive earthquake and should be repairable and not life-threatening.
- Patients, visitors, and medical, nursing, technical and support staff within and immediately outside the facility should be protected during an earthquake.
- Emergency utility systems in the facility should remain operational after an earthquake.
- Occupants should be able to evacuate the facility safely after an earthquake.
- Rescue and emergency workers should be able to enter the facility immediately after an earthquake and should encounter only minimum interference and danger.
- The facility should be available for its planned disaster response role after an earthquake.

High Risk Lifelines: Certain critical facilities designed to remain functional during and immediately after an earthquake may be able to provide the public with only limited services if the lifelines that they depend on are disrupted. Our understanding of the seismic hazards to new and existing lifeline facilities relies in great part on the several workshops and publications dedicated to the subject, including research completed as a result of the 1989 Loma Prieta earthquake. The issue of seismic hazard mitigation for lifelines is very complex, given the diversity of lifeline facilities. The general comments on the effect of strong ground motion to buildings apply to structures from where a given lifeline service is provided, such as the control tower in an airport, or the buildings housing the computers and telephone circuits central to the communication lifelines of a district. Properly designed, manufactured and laid out buried pipelines, in general, are not damaged by strong ground motions, but can be severely disrupted in areas of surface rupture, liquefaction, or landsliding. Some freeway interchanges and bridges have been damaged by strong ground motions in past earthquakes; certain bridge designs have been prioritized in retrofitting programs because of their poor past performance in liquefiable areas.

The hazard analysis focuses on four lifeline categories: water and sewer facilities, transportation facilities, electric power facilities, and gas and liquid fuel lines. Retrofit and upgrading programs for lifelines generally require careful planning to ensure that the public is not inconvenienced by irregular or discontinued service. The extensive systems of cable and pipe used to distribute electrical energy, gas, telephone communications, and water, or to collect sewer and storm drain water also require that potential problem spots in the system be identified and prioritized for an effective mitigation program to be implemented.

Development Located in Seismically Hazardous Areas: Buildings or critical facilities vulnerable to surface fault rupture or liquefaction should be given special attention in earthquake hazard reduction programs. Areas of high seismic risk can be defined within the context of the following overview:

- A hypothetical earthquake of approximately magnitude 6.8 on the Newport-Inglewood fault is predicted to generate Modified Mercalli intensities of IX in the northeastern and south portions of the City underlain by poorly consolidated alluvial and beach sand deposits, and where ground water occurs within 50 feet of the surface. The rest of the City is likely to experience Modified Mercalli intensities of level VIII, with damage to poorly reinforced structures, and partial or total collapse of unreinforced structures.

- Some of the sediments present along the beach, in the southern portion of the City along Lincoln Boulevard, and in the northeastern section of the City, in the area of the Santa Monica fault, may not be adequately compacted. Coupled with shallow ground water levels documented in these areas, these sediments are susceptible to liquefaction during an earthquake such as the hypothetical Newport-Inglewood event. Damage levels as high as Modified Mercalli intensities of XII could be registered in areas where liquefaction may occur.

- The areas of the City with a high to moderate susceptibility to liquefaction are relatively flat, with slopes generally averaging less than three percent (equal to dropping 30 feet in elevation within 1000 feet horizontally). Ground failure types associated with liquefaction that could impact the City include loss of bearing strength, where structures lose support or settle as the soils densify, and lateral spreading, where surficial blocks of sediment move downslope destroying foundations, utility lines and transportation corridors (Youd, 1978).

- The Santa Monica fault has the potential of rupturing the surface during an earthquake on this fault system. Surface rupture as a result of the worst-case earthquake scenario on the Newport-Inglewood fault is not expected to occur within City limits.

The following hazard analysis for the City of Santa Monica relies heavily on the discussions on strong ground motion, surface rupture and liquefaction susceptibility addressed in Sections 2.1 through 2.3. The analysis focuses on the seismic vulnerability of some of the critical facilities and infrastructure in Santa Monica. The Safety Element and Policies Report addresses some of the issues and opportunities that may be implemented to mitigate some of the hazards identified herein.

1.4.1 Hazard Analysis

Potentially Hazardous Buildings

Unreinforced masonry (URM) buildings are particularly weak during an earthquake, and unretrofitted pre-1934 masonry buildings are most likely to experience structural damage in a major near-field earthquake (Deppe, 1988). The City of Santa Monica has adopted several ordinances that have provided, to a limited extent, for the mitigation of seismic hazards associated with unreinforced masonry structures. The City's URM inventory was completed in 1977-78 by Council directive. As a result of the State Unreinforced Masonry Law (Assembly Bill 547) of 1986, Santa Monica has adopted an ordinance that will require mandatory upgrading of unreinforced buildings built prior to 1933. Upgrading and reinforcement of URM's is ongoing within the City. The City has identified 254 unreinforced buildings in its jurisdiction. Of these, about 100 have been upgraded to various standards of performance and have been excluded from the City's inventory of URM buildings to be targeted for upgrading. The inventory also excludes residential structures comprised of five or less units. The rest of the City's URMs will be targeted by the ordinance (The Planning Corporation, 1991).

Of the inventoried URM structures in Santa Monica, several Class I "high-risk" buildings (with more than 100 occupants) are located in the old commercial district in town, between Ocean Boulevard and Third Street, and between Broadway and Wilshire. This area of Santa Monica has been identified as having a moderate to low susceptibility to liquefaction, with liquefaction susceptibility decreasing with increasing distance away from the beach. Two other Class I "high-risk" URMs are located in the area of high liquefaction susceptibility near the intersection of Ocean and Pico Boulevards (see Plates 1 and 5).

Several other types of buildings have a history of poor performance during earthquakes. Of these, soft-story buildings are a concern in Santa Monica given the high density of this building type in the City. A large number of structures in Santa Monica are also pre-1952, single-family residences. These structures, built before the 1952 Uniform Building Code was implemented, can slip off their foundations as a result of strong ground shaking. Massive pre-1972 concrete buildings and structures are more likely to be damaged during an earthquake than similar buildings of more recent design that incorporate steel reinforcements (EERI, 1986). Pre-1971 commercial buildings with tilt-up construction, if not retrofitted, are also prone to structural damage, specially if subject to foundation distress because of liquefaction.

Essential Critical Facilities

Hospitals: Santa Monica has two acute-care hospitals, St. John's Hospital and Health Center, located at 1328 22nd Street, and Santa Monica Hospital Medical Center, located at 1250 16th Street. These facilities have 136 and 140 beds, respectively (Toppozada et al., 1988; Michael Brandman Associates, 1992). Neither facility is located within a liquefaction susceptibility zone. Strong ground motions in this area of the City where the hospitals are located can be expected to cause damage levels, measured in Modified Mercalli intensities, as high as X for a hypothetical maximum credible earthquake on the north branch of the Newport-Inglewood fault. The oldest building in the Santa Monica Hospital Medical Center complex was built in 1973, and may have incorporated the stricter design standards for hospital buildings. Other buildings in this complex were built as recent as 1986 (Santa Monica Hospital Engineering Division, personal communication, 1991). The various wings comprising the St. John's Hospital and Health Center range in age of construction from as early as 1942 for the Main Wing, to as recent as 1980-1981 for the East Wing (St. John's Hospital Construction Section, personal communication, 1991). The older wings in this hospital complex have not been retrofitted to more current construction standards, and could therefore incur damages that could render portions of the hospital nonfunctional as a result of an earthquake.

Both hospitals are located within five miles of the Newport-Inglewood fault zone. Toppozada and others (1988) predict that a hypothetical maximum credible earthquake on the Newport-Inglewood can render up to 50 percent of the existing hospital beds within five miles of the fault zone unavailable due to structural damage, restricted access, or disrupted utilities. The medical facilities in Santa Monica, assuming that they remain functional, could be stressed if other hospitals closer to the Newport-Inglewood fault zone are damaged and cannot provide medical assistance. Hazard management programs need to consider the issues of loss of life and injuries to staff personnel and patients, any physical damage to the buildings that may make them unoperational, loss of medical supplies and equipment, and loss of hospital function due to disrupted utilities or access problems (Toppozada et al., 1988). A hospital, even if functional, may also be evacuated after an earthquake if the staff or public officials lose confidence in the structural safety of the building, or if for example, a release of hazardous substances in the area, or even within the hospital, requires the evacuation of the neighborhood. Functional hospitals and small medical centers located nearby should be identified and targeted as essential components of an emergency preparedness plan.

Fire Stations and Police Stations: Santa Monica has four fire stations and four police stations. The location of these critical facilities is shown on Plate 5. These critical facilities should occupy buildings designed to remain functional in the event of the maximum credible earthquake on the Newport-Inglewood fault. The police substation located on the Santa Monica Pier is in an area identified as having a high liquefaction potential. The Bicycle Patrols and Structures Guards Police Station on 4th Street, and the Main Police Station in City Hall, are located very close to areas identified as having a low to moderate susceptibility to liquefaction, respectively.

Fire and police personnel can use the information provided herein and the earthquake scenarios developed by Toppozada and others (1985) for a magnitude 7.0 earthquake on the Newport-Inglewood fault) and by Davis and others (1982) (for a magnitude 8.3 earthquake on the San Andreas fault) to develop contingency plans and emergency drills applicable to the kinds of damage expected in different parts of the City if a major earthquake occurs. For example, given the concentration of manufacturing facilities in the area between Colorado Boulevard and the Santa Monica Freeway, the fire station on 25th Street, off Clover Park, may have to deal with earthquake-induced spills of hazardous substances and other emergencies in the manufacturing plants located within the surrounding area or within the area of high liquefaction susceptibility in the northeastern portion of the City. The stations on 7th and 19th Streets, on the other hand, are more likely to be called to suppress fires in the commercial zones off Wilshire and Broadway Boulevards, and in the downtown district. The station off 2nd Street and Hollister Avenue may be required to suppress fires in the commercial zone off Main Street, or to help with evacuation of residents in the areas highly susceptible to liquefaction in the southeastern corner of the City and along Ocean Boulevard.

High-Risk Critical Facilities: Refer to Chapters 4 and 6 for further information on the seismic risks of dams and flood control structures, and of facilities using or storing hazardous materials, respectively.

High-Occupancy and Dependent Care Facilities

High-Rises and High-Occupancy Buildings: Most of the high-rises in Santa Monica are located near the intersection of Ocean and Wilshire Boulevards, in an area of moderate to low liquefaction potential. If a major earthquake generates seismic intensities greater than VII in this area, the underlying sediments could liquefy with a resultant loss of bearing strength. Large structures, such as high-rise buildings, may settle several feet below grade. Because high-rises generally have high natural periods, the large amplitude seismic waves characteristic of a far-field earthquake are more likely to cause damage to this type of building than a near-field earthquake. A building's specific reaction to an earthquake, however, is dependent on several factors. Site-specific analyses that include a study of the underlying sediments are necessary to characterize more accurately the effect of strong ground motions on a building.

Other high-occupancy buildings, including shopping centers, and large theater auditoriums should be checked and upgraded, if necessary, to withstand strong ground motion during a major earthquake. This is a prudent element of an earthquake-preparedness program given the potential for major loss of life and injuries if one of these structures collapses during an earthquake. Evacuation of high-occupancy structures can be particularly difficult and taxing to earthquake relief operations if heavy rescue equipment is necessary. Earthquake-induced fires in these structures can also compound the difficulty of rescue operations.

Dependent Care Facilities: Schools and other dependent care facilities in Santa Monica should be addressed on a site-specific basis as part of a seismic vulnerability assessment. All schools will be subject to the strong ground motion predicted to occur in a worst-case earthquake, but some facilities are more vulnerable than others to seismic hazards. Lincoln Junior High School, Franklin School, McKinley School and Roosevelt School have been designated emergency evacuation shelters by the City. The grounds of the McKinley and Santa Monica Alternative Schools are located in areas of moderate to low liquefaction potential.

Lifeline Utilities

Water and Sewer: Santa Monica is supplied with water by the Santa Monica Water Department, who buys about 60 percent of the City's water from the Metropolitan Water District (MWD). The rest of the water used by Santa Monica comes from ground water sources. The primary transmission and secondary distribution water mains traversing the City are shown on Plate 6. Refer to Chapter 4 for further information regarding the seismic vulnerability of the City's water reservoirs.

Water pipelines can be damaged by liquefaction if significant vertical or horizontal displacements of the ground occur. Pipes can also break as a result of fault rupture, or, in some instances, due to the effects of high frequency seismic waves (NCEER, 1989). Far-field earthquake sources generally have less of an impact on the water supply distribution system than a near-field earthquake, unless localized liquefaction occurs. The age and type of pipe used in the water mains may also dictate how much damage could be incurred by this lifeline system in the event of an earthquake. Michael Brandman Associates (1992) indicate that more than 60 percent of the City's water supply mains are made of cast iron and are over 50 years old. The City is currently replacing these mains at a rate of about 20,000 lineal feet of main per year. Old cast-iron pipes, such as those common in the City, have a poor earthquake performance history. Breaks in the water distribution pipelines can result in significant reductions in water pressure with consequent adverse effects if water is needed immediately after an earthquake for fire suppression efforts. Chapter 5 includes further information on the City's water resources as it pertains to fire suppression capability.

The sewage collection system is owned by the City and maintained by the Utilities Office of the General Service Department. Sewage is treated at the Los Angeles Hyperion Treatment Plant located about 4 miles southeast of Santa Monica. The sewer system consists of about 750,000 lineal feet of pipe plus the Moss Avenue pumping plant which conveys sewer flow to the Coastal Interceptor (Michael Brandman Associates, 1992). Major waste water pipelines in Santa Monica are located in the western part of the City, along Palisades Beach Road (Pacific Coast Highway), Ocean Boulevard, and Main Street (see Plate 6). This area of the City has a high liquefaction potential. Secondary lines extend in a northeast to southwest direction along Colorado Boulevard, portions of Olympic Boulevard and the Santa Monica Freeway, and along Oak Street.

Contamination of drinking water may occur if both waste water and water distribution pipelines break in the same area. This could happen, for example, along portions of Broadway Boulevard and 26th Street, where water lines parallel large diameter sewer lines.

Transportation Facilities: Primary transportation facilities in the City of Santa Monica include the Santa Monica freeway and surface-street networks. Although a comprehensive study of individual transportation corridors was beyond the scope of this report, general comments regarding the seismic vulnerability of these facilities can be made.

Of the major streets in the City, a few extend through areas of high liquefaction potential. The northeastern sections of Colorado, Broadway and Santa Monica Boulevards extend through the high-liquefaction susceptibility zone in the northeastern corner of the City. The southern end of Lincoln Boulevard crosses a moderate to high liquefaction susceptibility zone. Pacific Coast Highway parallels the boundary between the high and moderate liquefaction susceptibility zones. In the event of an earthquake on this branch of the Santa Monica fault, a nearly one-mile stretch of road could be severely disrupted. This section of the Boulevard is also seated on sediments with a moderate liquefaction potential. The California Incline is located within the landslide potential zone that may induced by seismic shaking. Access through the McClure tunnel may be severely restricted by fallen debris following an earthquake.

A damage assessment of the 1989 Loma Prieta Earthquake suggests that structures located in liquefiable areas are at risk of foundation distress during a seismic event. Since then, the Los Angeles County Transportation Commission (LACTC) has recognized that freeway structures should be assessed for liquefaction hazards on a site-specific basins, and if warranted, retrofitted. LACTC (1990) has also issued a listing of high-priority structures that could be out of service after a major earthquake, such as a maximum probable event on the Newport-Inglewood fault. Many of these structures have also been targeted by Caltrans as part of a retrofit program aimed at upgrading the seismic design of State highways. Most of the structures identified are single-column bridges, which are known to be particularly susceptible to damage during an earthquake. The LACTC (1990) listing includes the interchanges between I-405 and I-10, which although not within Santa Monica, could have an impact on the City if their damage would require that temporary alternate transportation corridors be established.

Given the possible collapse of several freeway structures vital to the transportation corridor that services Santa Monica, post-earthquake plans should include alternate routes to be used in the short-term by rescue and relief vehicles. The County of Los Angeles has designated several roads as disaster routes. These routes are to serve as major transportation corridors in the event that a major disaster disrupts the freeway system. The disaster routes delineated through the City of Santa Monica are shown on Plate 7. This plate also includes the Emergency Evacuation Transportation routes established by the City to transport evacuees to various emergency evacuation shelters.

Alternate emergency or disaster routes should ideally avoid high- risk freeway interchanges and bridges; be at grade, wide and unflanked by potentially hazardous buildings that if collapsed may block the roads; avoid unstable slopes or high road cuts, and avoid areas vulnerable to liquefaction or fault rupture. Some of the County disaster routes shown on Plate 7 do not meet all these requirements; notably, the section of Pacific Coast Highway extending immediately below the Palisades Park in the northwestern portion of Santa Monica, where earthquake-induced landslides could sever this transportation corridor. This same section of road is also seated on sediments that may be highly susceptible to liquefaction. The northeastern section of Olympic Boulevard, also a County disaster route, is also, as mentioned above, located in an area of moderate liquefaction potential. If these routes are damaged during an earthquake, alternate routes will have to be designated by local officials as the need for access arises.

Sections of the Emergency Evacuation Transportation routes designated by the City of Santa Monica may also prove to be inadequate in the event of a major disaster. Collapsed buildings may block some roads, requiring that alternate routes be identified. Some of the areas these evacuation routes are intended to serve are also located in areas with moderate to high liquefaction susceptibility. Damage to structures located along these routes, and to the roads themselves, would hinder evacuation and emergency relief efforts. Some of the designated evacuation shelters may also be impacted by strong ground motion or liquefaction failures (see section on Dependent Care Facilities, below). The evacuation routes serving Section No. 5, the Edison School Shelter site, are most likely to be effected if a moderate to strong earthquake induces liquefaction in this area of the City, or if the Santa Monica fault moves and ruptures the surface.

Santa Monica's Municipal Airport is located in the southeastern corner of the City. No fault rupture area susceptible to liquefaction have been designated in this area. Any damage to the airport from an earthquake can be expected to be the result of strong ground motions. Damage may include broken windows in the air tower and passenger terminal buildings.

Electrical: Santa Monica is supplied with electrical power by the Southern California Edison Company. Transmission substations are the most vulnerable element of the electrical power delivery system. Switches, circuit breakers, massive transformers, control equipment and high-voltage porcelain insulators are particularly susceptible to high-frequency ground motions characteristic of a near-field earthquake (Hayes, 1988). Seismic intensities as low as VII can seriously disable this segment (Toppozada et al., 1988).

Five Southern California Edison electrical substations service the City; these are shown on Plate 6. None of the substations are located in areas susceptible to liquefaction. Damage to these substations, therefore, can be expected to be the result of strong ground motions. If one or more of these substations is damaged during an earthquake, some sections of the City may be without electricity. Critical facilities such as hospitals and the Police Department's Emergency Operation Center should be able to function on back-up power and small generators while energy is restored. If only limited energy can be restored to the City immediately after an earthquake, these critical facilities should be given priority in the allocation process.

The City of Santa Monica has extensive runs of buried transmission cable. These cables are generally buried in such a manner that two to three feet of play are allowed, however, some cables may be damaged as a result of liquefaction-induced displacements of the ground, or as a result of surface rupture along the trace of a fault. Some sections of underground cable are buried in areas of moderate to high liquefaction potential in the northern industrial corridor and southeastern Lincoln Boulevard to Marine Park portions of the City. The Santa Monica fault also projects through areas where major trunk lines are located. Overhead electrical lines generally de-energize automatically if electrical flow is interrupted. Planning considerations, however, should not discount isolated incidents where this does not occur. Fallen transmission lines can drain vital manpower resources if each individual line has to be checked to verify that it does not pose an electrical or fire hazard (Schiff, 1988). Lack of electrical energy can also impair communications, specially computers, and water distribution systems. Communication centers should have back-up capabilities that rely on radio waves rather than electricity. Gravity-fed distribution systems should be available as part of a redundant fire-suppression emergency program.

Natural Gas and Petroleum Pipelines: The City is supplied with natural gas by the Southern California Gas Company. The major gas transmission lines are shown on Plate 6. The lines in the northeastern and eastern areas of the City extend through the area of moderate to high liquefaction susceptibility. If the gas pipelines in these areas are damaged as a result of an earthquake, it would result in service disruption, and is some cases, fire. Gas leaks can occur at the connection between the distribution supply mains and the pipes leading to individual buildings. Damaged valves, small diameter pipes, and service connections would be expected in any area where liquefaction or surface rupture occurs. Damaged gas line connections, overturned appliances, and malfunctioning electrical facilities would also cause fires throughout the City. Chapter 4 presents a vulnerability assessment of fire hazards in Santa Monica where the impacts of an earthquake on gas mains and water distribution pipelines are discussed.

A 10-inch diameter steel pipeline carrying crude oil extends across the City in a northwest to southeast direction, along 26th Street and Cloverfield Boulevard (Plate 6). The pipeline is buried three to four feet underground, and slopes downward to the south. This 40-year old line has reportedly ruptured at least three times in the past, but none of these incidents occurred within Santa Monica city limits (City of Santa Monica Hazardous Material Incident Contingency Plan, 1990). The pipe is reportedly equipped with safety valves that are activated in case of line rupture. A small section of this pipeline extends through the high liquefaction susceptibility area identified in the northeastern portion of the City. If this pipeline were damaged as a result of an earthquake, localized contamination and disruption of service can be expected. The risk of fire from these spills is considered to be low (Toppozada et al., 1988).

CHAPTER 2: GEOLOGIC HAZARDS

The geologic hazards of greatest concern to Santa Monica include coastal slope instability and erosion, subsidence potentially related to ground water withdrawal and uncertified fills, and surface rupture hazards associated with earthquake events on the Santa Monica fault. Coastal bluff failures in the region of Pacific Palisades Park are known to have occurred. Clay mining operations since the early 1900's in the central portion of the City resulted in excavations that were backfilled with uncertified fills and in some cases they were utilized as landfills. Santa Monica currently receives approximately one-half of its water from ground water sources beneath the City. Subsidence, as well as salt water intrusion is known to occur along coastal areas to the south of the City, however, no subsidence or salt water intrusion has been reported within the City to date.

2.1 COASTAL BLUFF STABILITY

The City of Santa Monica is predominantly comprised of areas of low relief. Elevations begin at sea level, and gently rise to the northeast. The greatest elevations within the City are located in the area of Mount Olivette Reservoir, in the Franklin Hill portion of Santa Monica, at an elevation of approximately 375 feet above sea level, and is underlain by terrace deposits and Pico Formation bedrock. Slope instability issues are of concern in the bluff areas along the portion of the coast north of McClure Tunnel. These bluffs are located within Pacific Palisades Park. The southwest-facing bluff is situated along the landward side of Pacific Coast Highway for approximately 1.8 miles from the northwest boundary of the City to the McClure Tunnel on the southeast. Slope heights range from about 50 to 150 feet, and slope angles range from approximately 35 degrees to near vertical. The bluffs are composed of Pleistocene alluvium, that overlies Pleistocene marine deposits. The alluvial layers are horizontally bedded. The underlying marine deposits consist of stiff hard blue-gray clay and fine sand, and where affected by surface runoff and erosion, they form flatter slopes at the base of the bluffs.

On August 26, 1956, a section of the Park below Marguerita Avenue fell approximately 135 feet, taking four women with it, down to Pacific Coast Highway. Fortunately the women survived, and public demands for remedial action resulted in funding for investigations and studies regarding the control and correction of landslides along Pacific Coast Highway in and north of the City of Santa Monica. Corrective measures which were considered included a berm at the top of the scarp to redirect surface runoff, ground water interception systems along Ocean Avenue, and flattening of the bluff slopes. Remedial measures undertaken have included providing positive drainage away from the top of slope-towards Ocean Avenue, as well as maintenance of landscaping along the Park.

Slope stability analyses (Crandall, 1990; Mark Group, 1989; Moran et.al., 1959, Evans, 1956) indicates that the bluff slope exhibits a satisfactory factor of safety for gross deep-seated stability. However, the upper near-vertical portion of the slope may be expected to generate "soil falls" during heavy rains, seismic events, subsurface seepage, or by excessive surface runoff over the slope. Moran et al. (1959) performed an intensive study of landsliding in the Pacific Palisades Park area, and reported that 16 slides related to 7 potential causes had occurred between 1930 and 1958. The report concluded that the cause of the majority of slides was water-related, including landscape irrigation and heavy rainfall. Seismicity may have played a minor role, as at least two slides occurred following the 1933 Long Beach earthquake. In addition, vibrations associated with vehicle traffic on Ocean Avenue and Pacific Coast Highway may have also played a role. The City has been subjected to extremely rainy years on the average of about once every decade since the 1930's. These periods have exacerbated existing slope instability problems.

The potential for earthquake-induced landsliding is present along the coastal bluff areas of the City. The bluff slope may be susceptible to shallow earthquake-induced slides in the earthquake scenario prepared by Toppozada and others (1988) that details the hypothetical effects of a 6.5 magnitude earthquake on the Newport-Inglewood fault. Earthquake-induced failures will occur predominantly within the near-vertical portions of the bluff slope. The predominant mode of earthquake-induced failure depends upon soil-type and current conditions. If the slopes are saturated by rainfall or landscape irrigation, the reduced shear strength of the soil materials will increase the size and extent of earthquake-induced landsliding.

Previous studies (Evans, 1956), point out that the heaviest seepage is observed within a coarse gravel deposit which overlies a stiff clay near the foot of the California Incline. In 1933 work began to construct a tunnel to intercept ground water within this strata. The tunnel was advanced approximately 100 feet into the side of the bluff, however, the tunnel eventually became blocked by deterioration of the timbers and gradual sloughing of the materials above. The tunnel was uncovered by the August 26, 1956 slide, and was shortly thereafter reconstructed and backfilled with crushed rock and a pipe system to intercept ground water in the area.

The California Incline, which connects Pacific Coast Highway at beach level with Ocean Avenue on the bluffs above, is an important element of the traffic system in the City of Santa Monica. Since the roadway was constructed in the 1920's, there has been a history of local soil slumping that has resulted in periodic distress to the roadway. The roadway is supported by underlying bluff soils except where it had eroded prior to construction. At these five locations the Incline is supported upon cantilevered bridge structures.

2.1.1 Hazard Analysis

Responsibility for the mitigation and prevention of slope instability problems below the Park falls primarily on public agencies. The landscape maintenance in the Park is performed by the City. The Street Maintenance Division clears streets of landslide debris. The City of Santa Monica (1975), has designated the portions of the Park in the vicinity of the cliffs as a "high landslide potential" area. Earthquakes may cause portions of the bluff to fail. Erosion of the bluff has resulted in distress to the California Incline.

Even minor bluff failure may have adverse consequences on emergency response. Rain saturated slopes could affect the run-out distance and velocity of soil slides (Harp and Keefer, 1985). If a potential soil slip is completely saturated, earthquake-induced shaking could liquefy and mobilize the soil slide downslope as a high-velocity debris flow. The 1971 San Fernando Earthquake triggered hundreds of small failures, however, the lack of large failures were attributed to the extremely dry conditions at the time of the event. Although at the present time there is not enough data to determine how much the risk of failures would be increased by ground shaking, it is apparent that some increase is likely.

According to a comprehensive study on landsliding in southern California (Geological Society of America, 1986), the bluff area below Pacific Palisades Park is essentially within a state of equilibrium with regard to stability. Slopes steeper than 60 degrees are reported to be stable, while slopes of less gradient are subject to erosion from rainfall. Slope stability analyses by Crandall (1990) attempted to quantify the relative stability of the bluff with respect to a calculated factor-of-safety. The results of their analyses indicated that the overall bluff slope exhibits a satisfactory calculated factor-of-safety for gross slope stability. However, the analyses concluded that the upper near-vertical portions of the bluff are susceptible to soil falls and that recession of the top of the slope within Pacific Palisades Park should be expected over the years.

For new development, the City Building and Safety Division presently enforces the 1991 UBC. The UBC establishes specific site investigation requirements and defines various standards by which a hillside project will be assessed. UBC provisions give the City Engineer a means for safeguarding new development by:

- Requiring preliminary investigations of tract sites by qualified geotechnical engineers and engineering geologists;
- requiring developers to retain the services of both disciplines during construction;
- requiring certification as to the stability of the building site to adverse effects of rain and earthquakes before issuance of building permits;
- assuring coordination between a civil engineer with the project engineering geologist and geotechnical engineer while supervising grading during construction; and
- requiring mitigation of onsite hazards caused by grading that may affect adjacent properties, including erosion and slope instability.

Plate 2 shows hillside areas susceptible to surficial slides, and erosion. It does not account for existing slope mitigation measures. In addition, the depiction of units are general and should not be used as a substitute for site-specific studies. It does, however, permit planning for the types of failures and potential slope problems that will predominate in a given area. The coastal bluff slope planning area, as defined in this Safety Element, is described as follows:

- "High Landslide Potential Risk Area" - defined on the coastal side as 100 feet west of the centerline of Pacific Coast Highway (Palisades Beach Road) from McClure Tunnel to the northwest City boundary; and on the landward side as 100 feet east of the centerline of Ocean Park Avenue (as shown on Plate 2).

Causes of past slope failure and erosion can be summarized as follows:

- According to an article appearing in the Evening Outlook on March 15, 1933, several slides had occurred from March 10 to 14, 1933 following the March 10, 1933 magnitude 6.3 Long Beach Earthquake. The largest failure directly associated with the event occurred at the foot of Wilshire Boulevard where a section of walkway and fence were carried to the roadway below. A failure occurring on April 29, 1956 at Georgina Avenue was attributed to a large crack at the edge of the bluff that first appeared following the 1933 Long Beach Earthquake. The fence along the headscarp of the cliff was repositioned inland from the ground cracking attributed to the earthquake to provide a safety margin.

- Seepage of ground water through a sand strata was directly attributed as the cause of the February 19, 1933 slide, which resulted in a cliff segment about 20 feet long and 6 to 8 feet wide, at the foot of Georgina Avenue failing. This failure also carried two persons down with it who escaped serious injury (Evening Outlook, 1933). Many early City workers attributed the bulk of slides occurring in the Pacific Palisades Park area to ground water seepage. An interception system consisting of a ±100-foot long tunnel with two cross-cut segments was constructed beginning in August, 1933, to help intercept ground water.

- Several slides associated with a Park segment approximately 115 feet long and 20 feet wide occurring during July, 1934 were attributed, by members of the City engineering staff, to a combination of vibration caused by heavy traffic on Ocean Avenue, the newly widened Pacific Coast Highway and water seepage. In addition, a slide which destroyed three automobiles parked on Pacific Coast Highway on July 15, 1942, occurring approximately 200 feet southeast of Arizona Avenue was ascribed to similar causes.

- Heavy rains during February of 1937 were attributed to the cause of 6-inches of settlement damage of a ±50-yard segment of the California Incline. Record precipitation in March 1941 completely destroyed the lower end of the California Incline by washing out its foundation. Approximately 3.33 inches of rainfall within a 48-hour period preceded a Pacific Coast Highway blocking slide which occurred on January 16, 1952 at the foot of Georgina Avenue, and a second slide at the foot of Idaho Avenue occurring on January 18, 1952.

- An undetected broken water main located in the vicinity of Lincoln Park, approximately 2,500 feet northeast of the bluffs, discharged approximately 1,500,000 gallons of water into the subsurface from March 4, 1951 to September 26, 1951. This water may have followed one or more of the coarse grained horizons noted along the bluff face, and may have contributed to the cause of sliding which occurred on August 20, 1951 at the foot of California Avenue.

Evans (1956) postulated two chief mechanisms of sliding at the bluff:

1) Slides as a result of gradual "fatigue" of soils, that occurs in relatively dry soil. This fatigue, he believed, was due to periodic fluctuations in moisture content which developed fine shrinkage cracks. These forces are thought to be small, but continuously active. Evans (1956) attributed the slide on August 26, 1956 to this process.

2) Slides that are a result of an increase in water content of bluff material. The water increases the weight and decreases the cohesion of bluff materials, thereby, increasing the slide potential of the soil mass.

2.2 SUBSIDENCE/SETTLEMENT

Subsidence, as referred to in this section, is the gradual sinking of land caused by a decrease in pressure below the surface. Subsidence can also be caused by sudden changes in crustal stress related to large earthquakes, an issue examined in Chapter 1. The City of Santa Monica may be susceptible to subsidence from ground water withdrawal for domestic uses, as well as differential settlement of uncertified fills or landfills within the City. Clay mining activities in the central, industrial portion of the City resulted in open pits. In many cases these open clay pits were backfilled with uncertified fill or landfill materials.

Subsidence due to ground water withdrawal has not been documented to date, however, future subsidence due to depletion of the underlying aquifer should not be discounted. In addition, the strata underlying the City has been identified as a potential oil resource. Therefore, future subsidence associated with exploration of these resources should also be addressed by the Safety Element and Policy Report.

2.2.1 Hazard Analysis

Plate 2 shows the location of former surface depressions that may represent clay pits. These locations were obtained during a review of 1928 through 1962 aerial photographs of the Fairchild Collection located at Whittier College and U.C.L.A. In addition, many of the former pits are shown on the 1934 edition of the Sawtell, California quadrangle, which has a contour interval of 5-feet. The depths of these depressions, as indicated on the 1934 quadrangle, appear to range in depth from 10 to 30 feet. The deeper pits were located in the areas: between Cloverfield, Broadway, Olympic boulevards, and 26th Street; and in the vicinity of the Public Works Yard south of Exposition Boulevard and north of the Santa Monica Freeway. The remaining locations appeared to be shallow; approximately 10 feet in depth. Nearly all former clay pits were still open into the early 1960's. As gaps exist in the aerial photograph coverage and because smaller pit areas can be overlooked in small scale photos, the locations shown on Plate 2 should be considered approximate. However, the locations are useful for planning purposes. The area of clay mining appears to be confined to the central industrial corridor in the vicinity of Interstate 10.

Since the cessation of clay mining activities, many of the open pits have been backfilled. As the majority of locations are within the industrial and commercial portions of the City, the possible presence of hazardous waste within the fill materials should be expected. An open clay pit near the vicinity of Colorado Place was apparently backfilled with some municipal waste from the City of Beverly Hills (Johnson, personal communication, 1991). During a 1978 geology and soils investigation for a proposed parking structure, Crandall (1978) encountered debris and explosive gases in borings to depths up to 39 feet. This study evaluated approximately two city blocks north of Colorado Avenue and between Cloverfield Road and 26th Street. The geotechnical boring logs report mostly inert fill materials consisting of asphalt, wood, brick and concrete. The debris contents of the borings ranged up to 80%, and a reading of a potentially explosive gas mixture was encountered in one-boring. Uncertified fills to depths of approximately 15 feet were noted by Crandall (1989) in investigations for the proposed "Arboretum" south of Colorado Avenue between 20th Street and Cloverfield Boulevard. The issue of hazardous materials/waste is addressed in more detail in Chapter 5.

The hazards associated with the former clay pit areas typically encompass the entire city block containing the former clay pit areas. This is because the former clay pits pose multiple potential hazards, including differential settlement, explosive gases, and hazardous waste. As these former pit areas are relatively shallow, it is important to note the potential hazards they pose can be readily mitigated, and mitigation including removal of fill and landfill debris at some locations has already occurred.

The City of Santa Monica utilizes approximately 1,600 million gallons of ground water per year for delivery within the City limits (Harvey, personal communication, 1991). This quantity corresponds to roughly one-half of the water used by the City. However, no subsidence has been documented within the City due to ground water withdrawal. In addition, no drop in water levels have been noted in association with the recent drought years (Harvey, personal communication, 1991), which may indicate a stable subsurface supply with significant recharge rates. Furthermore, the City has closed several wells within the central industrial portion of the City, which may eventually result in ground water level increases.

The City may have an economically viable petroleum resource beneath the City (Bear and Kistler, 1967). Petroleum withdrawal has historically resulted in subsidence within many areas of the Los Angeles Basin, such as Baldwin Hills and areas of Long Beach. However, modern exploration typically involves injecting water in the subsurface to cause the oil to rise. This process, if completed properly, does not decrease the pressure below the surface, thereby preventing potential subsidence.

CHAPTER 3: INUNDATION AND SHORELINE EROSION HAZARDS

Government Code Section 65302 (g) requires local governments to assess the potential impact that a dam failure might have on their jurisdiction. This chapter reviews all published dam inundation maps showing flood limits projecting into the City. The reservoirs that impact the City includes: the Stone Canyon Reservoir, which is owned and managed by the Los Angeles Department of Water and Power; and the Riviera Reservoir which is owned by the City of Santa Monica. In addition, the City owns three 5-million gallon reservoirs; Arcadia, Mount Olivette and San Vicente reservoirs that may pose localized inundation hazards due to seiching during an earthquake. The low lying coastal areas within the City are susceptible to tsunami inundation in the event of a large distant earthquake, or an earthquake or undersea landslide within the Santa Monica Bay. Run-up studies for distant earthquakes are available for the City, however, tsunami run-up potential due to local offshore earthquakes or undersea landslides has not been assessed in detail. The Safety Element must also assess the impact of 100- and 500-year flooding, however, due to the extensive storm drain network within the City, flood hazard is classified as nil by the National Flood Insurance Program. The primary element of this network is the Kenter Canyon Drain, which consists of a 9 to 10-foot concrete arch pipe, and drains into the ocean at the western end of Pico Boulevard. Santa Monica plans and maintains the local storm drain network to control flooding (Plate 6). Although the storm drain system is expected to prevent surface flooding, shoreline and nearshore structures have historically been impacted by storm generated waves.

3.1 DAM/RESERVOIR FAILURE

Small portions of the City lie within the inundation limits of the Stone Canyon and Riviera Reservoirs, as shown on Plate 3. This section explores the operational function and emergency plans implemented by the dam owners, as well as other pertinent details on the individual dams, in order to better inform the City on this particular threat. The statutes governing dam safety are defined in Division 3 of the California State Water Code (California Department of Water Resources, 1986). It empowers the California Division Safety of Dams to monitor the structural safety of dams that are greater than 25 feet in dam height or 50 acre-feet in storage capacity. State jurisdiction is void relative to Federal dams, which are operated and maintained by the U.S. Army Corps of Engineers. By authority of California Government Code Section 8589.5, dams under State jurisdiction are required to have inundation maps that show the potential flood limits in the remote possibility a dam is catastrophically breached. Dam inundation maps are prepared by dam owners primarily for contingency planning; it is stressed that they in no way reflect the structural integrity or safety of the dam in question. Section 8589.5 also requires that dam owners prepare and submit emergency response plans to the State Office of Emergency Services, the lead State agency for the State dam inundation mapping program.

3.1.1 Hazard Analysis

The risk of dam inundation is not easily defined in terms of statistical probability, like 100-year or 500-year flood events. In order to qualitatively assess the threat of dam inundation in the City, a set of selected criteria are applied to each of the dams in question, which are in part derived from Federal Emergency Management Agency (FEMA) guidelines on dam safety defined in publication FEMA (1987-145). These criteria are meant only to assist Santa Monica in determining appropriate levels of risk-reduction actions and do not constitute a site-specific risk assessment. The following are general factors based on lessons learned from past dam failures and other planning considerations:

- Age - Older dams constructed of earthen and hydraulic fill material, if not properly maintained, are most susceptible to foundation failure. Older dams of concrete construction have a good safety record (FEMA, 1987-145).
- Construction - Based on a review of dam failures from 1900 through 1975, older earthen or hydraulic fill dams are considered most susceptible to foundation instability and overtopping; largely resulting from storm runoff exceeding the design capacity of the dam rather than from ground shaking during earthquakes (FEMA, 1987-145). Hydraulic fill is most vulnerable to earthquake shaking. Concrete dams, if constructed and sited properly, are most resistant to earthquakes; when they have failed historically, they have failed shortly after emplacement of water in the reservoir (FEMA, 1987-145).
- Operation - Compliance with State and Federal standards indicates proper seismic and structural evaluation, inspection, repairs, maintenance, and monitoring operations, and adequate regulation of water in the reservoirs to appropriate levels.
- Population/Critical Facilities - In areas that have already been developed, FEMA (1987-145) considers the population and sensitivity of land uses in the potential inundation area. The presence of critical facilities or high risk facilities in potential inundation areas may pose an unacceptable risk, regardless of the likelihood for dam failure.
- Flood Arrival Time - Approximate flood wave travel times from each dam to various locations along the inundation path are defined on owner-prepared dam inundation maps. Shorter wave travel times would require faster emergency response actions.

Stone Canyon - The inundation calculations prepared by the City of Los Angeles Department of Water and Power in 1975, indicate that several inches of water will impact industrial and residential areas in the eastern portion of the City, in the vicinity of the freeway corridor. According to the City's Draft Emergency

Response Plan, an estimated 5,000 Santa Monica residents may be affected. The Stone Canyon Dam is constructed of earthen fill material, and is approaching 70 years of age. The crest height of the earthen dam is 185 feet, and impounds 10,370 acre feet of water. The Division of Safety of Dams last verified the operational safety of the dam in February 1990. The reservoir is located approximately 4½ miles north of the City. In the event of a catastrophic failure, flooding of portions of the City would occur within twenty-four minutes.

Riviera Reservoir - This reservoir is owned by the City of Santa Monica and consists of a reinforced concrete tank located above the Riviera Country Club north of the City. The reservoir was constructed in 1962, and has a capacity of approximately 25 million gallons (Harvey, personal communication, 1991). The height of the reservoir is approximately 40 feet, the south and east walls are buttressed with compacted fill. The vertical reinforced concrete walls are keyed into the foundation, as well as the roof of the structure. The inundation calculations prepared by Delta Consulting Engineers (1974) for the City of Santa Monica indicate that most flood water from a potential rupture would be contained within the Santa Monica Canyon Tributary and flood control channels outside the City limits. However, the southern limits of the inundation area appear to reach areas within the City boundary north of La Mesa Drive that do not contain structures (Plate 3).

Mount Olivette Reservoir - This reservoir is owned by the City of Santa Monica and is located at an approximate elevation of 375 feet within the northeasternmost portion of the City, between Franklin and Centinela Avenue. According to the City of Santa Monica Water Division (Harvey, personal communication, 1991), only tank #3 with a capacity of 5 million gallons, is currently utilized. The tanks were constructed in 1949 and no inundation studies are currently available. This older tank may pose a localized hazard due to seiching or overtopping during a seismic event. However, a detailed evaluation would be necessary.

The most critical criteria in gauging dam/reservoir safety and inundation risk is compliance with State standards. Following annual safety inspections by the State, operational and maintenance recommendations are initiated by the dam owner in order to remain in compliance with State safety standards. All State and Federal Dams upstream from Santa Monica are in compliance with safety standards. Nevertheless, the Emergency Services Act (Government Code Section 8550) recognizes the State's responsibility for mitigating even unlikely hazards, especially the catastrophic potential for inundation. Most dam failures are not expected to occur instantaneously, if at all, during a major earthquake (Toppozada et al., 1988). In addition, the City of Los Angeles Department of Water and Power, who manages the Stone Canyon Dam, with the greatest potential inundation area within the City, maintains a Disaster Plan that results in an increase of warning time. The Department of Water and Power (LADWP) Disaster Plan includes provisions for:

- Emergency drawdown of water to reduce reservoir levels in the event of a strong earthquake, or a serious structural defect. The LADWP Water Operating Division reports threats to the dam and have emergency beepers to contact upper command personnel if anomalous or extraordinary circumstances warrant alert.

- Telemetered early warning signals from LADWP dams alert personnel of significant increases in seepage, a critical precursor that can undermine the foundation and threaten the stability of the dam. The signal is transmitted directly to LADWP headquarters where the Water Engineering and Water Operating Division may coordinate an alert to the LADWP Assistant General Manager or alternate internal authorities. The LADWP then reports directly to State Office of Emergency Services, Division of Safety of Dams, and the County Sheriff, the latter contacts individual cities.

3.2 TSUNAMI INUNDATION

One of the least understood natural hazards that threatens the entire west coast of the United States is from tsunamis. The term is derived from two Japanese words: "tsu" meaning harbor, and "nami" meaning wave. They have a wide size range and can travel at speeds up to 500 miles per hour (Griggs and Savoy, 1985) and are generated by vertical movement of the ocean floor in undersea earthquakes with Richter magnitudes usually greater than 6.5. Worldwide, over 51,000 people have been killed by 94 tsunamis in the last century (Bernard, 1988).

Tsunami inundation data from 1812 through 1974 (McCulloch, 1985) indicate run-up in southern California has varied from approximately one to six feet. Run-up in the Santa Monica area resulting from the Magnitude 8.3 Alaska earthquake, occurring on Good Friday in 1964, was approximately six feet. At Crescent City in northernmost California, the 1964 earthquake-induced tsunami resulted in 8-foot high waves along most of the city, causing 11 deaths and 11 million dollars in damage. The 1964 tsunami, produced wave heights of 4 feet in Los Angeles and Long Beach Harbors, resulting in approximately $200,000 in damages. There was no well-documented tsunami activity noted along the California coast following the 1906 San Francisco earthquake.

Coastal subsidence associated with a local tsunami producing event, perhaps occurring on the Malibu Coastal or Santa Monica compressional fault systems, should also be considered. Downwarping of coastal areas can result in inundation either by itself or in conjunction with a earthquake-induced tsunami. The 1971 San Fernando Earthquake was associated with a regional uplift of two meters, an expected result of a compressional thrust-type earthquake (Oliver, et al., 1974). Perhaps more significant, Oliver, et al. (1974) also documented broad areas of subsidence on the order of 1.6 meters accompanying the event. This suggests that the coastal areas such as Santa Monica may be subject to significant earthquake-induced regional subsidence.

Other near-field sources may include undersea slides, perhaps within the ±1,000 meter deep Santa Monica Canyon. Sediments may build up along the walls of a canyon, and slough toward the bottom of the canyon when triggered by seismic shaking. This and similar mechanisms result in vertical displacement of water creating a tsunami.

Numerical modeling of Houston and Garcia (1974) indicates 100- and 500-year tsunami run-up heights of approximately 10.4 and 16.6 feet, respectively, for the coastal areas of the City.

3.2.1 Hazard Analysis

Evaluation of vulnerability is typically conducted using either of three techniques - historical precedent, numerical simulation, or identification of seismic gaps where large tsunamigenic earthquakes may be expected. Because of the insufficient recorded history and the lack of knowledge in determining where and when large seismic events might occur within seismic gaps, numerical simulation is perhaps the best existing technique for assessing vulnerability in southern California. A number of attempts have been made to assess tsunami vulnerability using numerical simulation including the work of Goto and Shuto (1983), Liu and Earickson (1983), Houston and others (1975), and Houston and Garcia (1974). According to McCulloch (1985), the most recent Federal Emergency Management Administration (FEMA) study of flood hazard to selected areas of southern California was in 1982 (Lee and others, 1982). The 1982 study evaluated the flood-generating mechanisms from tsunamis generated along the Aleutian-Alaskan and Peru-Chile trenches. The 100- and 500- year tsunami heights developed by Houston and Garcia (1974) were used. The numerically modeled wave heights for these time intervals are approximately 10.4 and 16.6 feet, respectively. These run-up heights include the effects of astronomical tides.

Most of the progress in tsunami research has been limited to incoming waves from large distant sources. Waves of intermediate size, generated locally or regionally have not been given as much attention. These potential sources may include nearby undersea slides, or events occurring on the Malibu Coastal, Santa Monica or Palos Verdes fault systems within Santa Monica Bay. An additional concern would be a near-field tsunami producing event combined with tectonic coastal subsidence. The existing tsunami warning system for southern California is largely geared toward Pacific-wide tsunamis, that is tsunamis generated many thousands of miles away. The existing tsunami warning system for tsunamigenic earthquakes occurring along the west coast of the U.S., is operated by the Alaska Tsunami Warning Center. The system requires approximately 21 minutes to issue a warning for a tsunami generated off southern California. Even more time would be required to relay the warning to local agencies and to translate the warning into action (McCulloch, 1985). Once the decision has been made to issue a warning or watch, the messages are transmitted on the National Warning System telephone line. In California, the message goes to FEMA and to the State of California Office of Emergency Planning, which is manned 24 hours a day.

Tsunami Hazards Reduction Utilizing Systems Technology (THRUST) is a systematic approach to reducing tsunami hazards that is being developed by the U.S. Agency for

International Development's Office of Foreign Disaster Assistance (Bernard and others, 1988). Project THRUST has an established pilot system in Valparaiso, Chile. The general approach includes pre-event emergency planning, real-time assessment, and rapid warning via satellite communication links. It is a low-cost local tsunami warning system that can deliver life-saving tsunami hazard information on a timely basis. The THRUST system can deliver a warning of a tsunamigenic earthquake in as little as two minutes.

The three components that make the THRUST system so unique are:

- Pre-tsunami preparedness, consisting of historical data base studies, numerical model simulations, and development of a detailed emergency operating plan.
- Real-time local hazard assessment using seismic triggers with predetermined threshold levels.
- Rapid dissemination of information to local officials using the Geostationary Operational Environmental Satellite.

The work of Houston and Garcia (1974), is the most pertinent of the tsunami studies identified for the Santa Monica coastline. Their work was performed for the Federal Insurance Administration of the Department of Housing and Urban Development. They calculated tsunami of distant origin for much of the coastal western United States. These predicted run-up heights are roughly estimated to be in the range of those expected for a Magnitude 7.5 earthquake occurring offshore. In their, 100 year and 500 year run-up calculations, they considered effects of astronomical tides and tsunamis, as well as the local resonance effects due to near-shore bathymetry.

Houston and Garcia (1974) present probabilistic determinations of run-up heights along the coastline (see Plate 3); not the absolute maximum run-up that could conceivably accompany a tsunami. Their chief limitation was the very limited time interval for which there are historical data. Therefore, they feel the results of their run-up calculation predicted for both the 100- and 500-year time intervals have an average error of approximately ±40 percent for southern California. Inundation areas were purposely not shown in their study, as the model was not sophisticated enough to accurately show flood water heights and water velocities while simultaneously taking into account onshore topography and land-based structures (Garcia, personal communication, 1989; Camfield, 1987).

Plate 3 shows the 500-year run-up value of 16.6 feet from Houston and Garcia (1974) for the Beverly Hills quadrangle. The limit of tsunami inundation shown on Plate 3 was generated by extrapolating the wave height inland to the corresponding topographic contour to provide some insight to the actual area that could be inundated. Hwang and Lee (1979) suggest that because recurrence remains the least understood parameter in determining tsunami risk for southern California, the larger recurrence interval (500-year) is more appropriate for planning purposes. Supporting the more conservative run-up heights calculated for the 500-year tsunami is also in general agreement with the correlation of historical run-up heights in southern California (6 to 12 feet) and the predicted run-up heights (2 to 16 feet). An increase in run-up due to tectonic coastal subsidence associated with a locally generated tsunami is not addressed by these numerical simulation studies. Perhaps the most viable method, at this time, to determine large scale coastal movements is to conduct a detailed study of the marine terraces along the coast, and compare the movements with their landward counterparts within the Los Angeles Basin.

3.3 SHORELINE EROSION

The low lying beachfront area within the City of Santa Monica are susceptible to erosion due to storm generated sea waves, as well as a postulated global rise in sea level. Storm generated sea waves have historically damaged near-shore structures within the City. The Santa Monica Municipal Pier suffered damage as recently as 1988, and major damage during the winter of 1983, when storm generated waves combined with high tides resulted in millions of dollars damage to coastal southern California. A short breakwater segment is present west of the Pier.

In addition to erosion by storm events in combination with high tides, the postulated rise in global sea-levels may play a role in community planning in the coming decades.

3.3.1 Hazard Analysis

Scenarios of sea-level rise developed by the Environmental Protection Agency range from 1.9 to 12.1 feet by the year 2100. These results, however, are based upon elaborate numerical models, estimated ranges of future consumption of fossil fuels, and estimates of processes that are poorly known. Rational decisions on mitigation of shoreline erosion require accurate estimates of beach erosion, as well as an understanding of how those rates are influenced by sea-level rise.

There are three basic methods of mitigating shoreline erosion:

- Hard structures such as sea walls (hard stabilization).
- Sand replenishment (soft stabilization).
- Relocation of structures away from beach.

Determining the mitigation measure required depends on technical, economic, and environmental considerations, as well as community priorities. Hard stabilization, such as sea walls, have come under close scrutiny in recent years due to documentation of these structures impeding natural beach replenishment. Sea walls often end up with a degraded or non-existent beach in front of them. However, some researchers (Houston,

1988) maintain that properly designed hard structures do not intercept the natural littoral flow of sand. Soft stabilization involves placing large quantities of sand to advance the shoreline seaward. The most common natural source of beach sand, southern California rivers, has been effectively cut-off. Beach replenishment has been the most common method utilized along southern California beaches. This method is frequently used to compensate for decades of erosion. Nourishment is most appropriate when shoreline systems are only slightly out of balance. Proper replenishment requires nourishment of the entire near shore profile, rather than just the upper beach (Houston, 1988). Maintaining the shoreline position in Santa Monica may cost less than removing structures and allowing the shoreline to retreat. If maintaining the shoreline proves more costly, relocation could be more attractive. The best time for relocation would typically follow a severely damaging storm. The relocation option should be considered on a case by case basis, involving public hearing and participation by those affected.

CHAPTER 4: FIRE HAZARDS

The vast majority of the City of Santa Monica is developed. Residential areas compose 43.5 percent of the City's developed acreage, with 68 percent of the available housing contained within areas north of Montana and Sunset Park. High-density residential and commercial structures and several high rise buildings are present in the western sector of the City, while commercial and manufacturing facilities comprise the central one-third. Multi-family buildings containing five or more units make up 66 percent of the City's housing. Data from the Fire Department for 1989-90 and 1990-91 fiscal years indicate that of fires involving structures, nearly all were attributed to residential and commercial buildings. Fires in industrial districts highlight the threat of hazardous materials incidences, an issue discussed in more detail in Chapter 5. Mid-rise, high-rise buildings, and high occupancy buildings and/or buildings housing immobile populations add special fire fighting logistical demands.

4.1 FIRE PREVENTION AND SUPPRESSION

The Santa Monica Fire Department responded to over seven thousand calls for service in both 1991-92 and 1992-93 fiscal years. Fire service consisted of the following:

	1991-92	1992-93
Structure Fires	150	119
Vehicle Fires	99	98
Non-Occupancy Fires	274	196
TOTALS:	523	413

Total emergency medical aid responses were 4,730 for 1991-92, and 5,477 for 1992-93. Total calls other than fires, which include rescue, service, false alarms and accidental alarms, were 2,173 in 1991-92 and 6,659 in 1992-93. Over 90 percent of the dollar loss due to fire in 1991-92 and 1992-93 were attributed to structural fires. Of structural fires resulting in greater than $10,000 damage during the 1992-93 fiscal year, nine were attributed to commercial buildings, while eight impacted residential structures. Per capita loss due to structural fires was $17.52 in 1991-92 and $15.91 in 1992-93.

While this chapter is concerned with fire prevention and suppression, it is important to note that other services are provided by fire departments. Such services can negatively impact availability of fire suppression resources in an earthquake. The threat of earthquake-induced fire is emphasized because widespread fires following an earthquake, coupled with Santa Ana winds, essentially constitute a worst-case fire suppression scenario. Despite the fact that the most common cause of urban and wild land fires is man, fire safety can be readily gauged using such a scenario as a standard.

A discussion of earthquake or non-earthquake fire hazards hinges on the City's efforts to prevent fires and to suppress them once they have started.

Assessment of the City's fire protection can be partially gauged by the following:

Fire Fighting Readiness: There are 4 fire stations that serve Santa Monica with 8 first response units available for fire suppression and emergency medical service. A breakdown of Fire Department capabilities is presented in Table 5.1. The City received a ranking of 2, on a scale of 1 to 10, with 1 being the highest rating, by the Insurance Service Office (ISO) of California in 1992 for fire protection capabilities. The Fire Department has established 8 running districts to insure minimum response time. The running districts specify which companies are dispatched and the order in which they will arrive on scene. Initial structural fire response typically includes 2 engines, 1 truck, 1 squad, and 1 command vehicle. Both the squad units within the City, and 4 of the engines have paramedic capability. Response times to anywhere in the City under normal conditions average 4 minutes. The City's resources for fire fighting can be augmented by contacting the Region 1 Area A Coordinator who will notify local fire agencies, including Culver City, Beverly Hills, Los Angeles City, and Los Angeles County.

Minimum Safety Standards for Peak Load Water Supply, Road Width, and Turning Radius: Minimum standards function as safeguards to ensure public safety and prevent unsafe development. Peak load water supply standards ensure sufficient water flow is available to fight fires. The City Engineer determines actual peak water flow requirements based on building type, design, and use. Required minimum peak load water supply rates, are divided into three pressure zones, as follows:

- The 500 foot zone is located within the northeast portion of the City and occupies the highest elevations within the City. This area is supplied by MWD water, which has a sufficient pressure head to serve the area without pumping.
- The 350 foot zone, covers the northern and central portions of the City. It is served by the MWD, as well as local treated water.
- The 250 foot zone, is located within the predominantly low lying southwestern portion of the City and is supplied primarily with local treated water.

Minimum road right-of-way is defined to avoid situations where emergency access is restricted due to narrow street width. Minimum road width is 20 feet for residential neighborhoods; 25 feet for commercial development and any area where onsite fire hydrants are required. Turning radii on cul-de-sacs or street curves determine the maneuverability of fire department vehicles; small radii can restrict emergency access. Minimum turning radii standards for emergency accessways are 40 feet inside and 50 feet outside. Minimum standards for road width and turning radii are geared for private driveways.

Table 4.1 - FIRE DEPARTMENT CAPABILITIES

CITY OF SANTA MONICA FIRE DEPARTMENT CAPABILITIES

EQUIPMENT	
Station #1 (Headquarters) 1444 7th Street	Engine Company (Paramedic)
	Truck Company
	Squad (Paramedic)
	Rescue
	Command Vehicle
Station #2 220 Hollister Avenue	Engine Company (Paramedic)
	Engine (Reserve)
	Squad (Paramedic)
	Utility Vehicle
	Mechanics Vehicle
Station #3 1302 19th Street	Engine Company
	Engine (Reserve)
	Squad (Reserve Paramedic)
	Trench Rescue Vehicle
Station #5 2450 Ashland Avenue	Engine Company (Paramedic)
	Rescue (Airport)
	Engine (Reserve)
	Truck (Reserve)

PERSONNEL

Number	**Description**
1	Fire Chief
7	Battalion Chiefs
19	Fire Captains
18	Engineers
57	Firefighters
1	Arson Investigator
1	Assistant Fire Marshall
4	Inspectors
1	Safety Specialist
1	Dispatch Supervisor
4	Dispatchers
2	Mechanics
1	Administrative Analyst
4	Secretaries

Planning: The National Board of Fire Underwriters recommends a three-day emergency supply. The Land Use and Circulation Element estimates that a three-day emergency supply for Santa Monica is 35 million gallons. Four City reservoirs maintain a reserve capacity of 42.6 million gallons. The Arcadia Reservoir, located just east of the City, has a five million gallon capacity and supplies the 250 foot zone by gravity feed. The Arcadia Reservoir also supplies water to pumping stations that service the 350 foot zone. The five million gallon Mount Olivette Reservoir is located at an elevation of approximately 375 feet in the northeasternmost corner of the City, and supplies the 350 foot zone with gravity fed water. The San Vicente Reservoir, located in the northeastern portion of the City, has a capacity of 5.1 million gallons, and serves the 350 foot zone. The City owned Riviera Reservoir is located above the Riviera Country Club north of the City boundary, and has a capacity of 25 million gallons. Emergency pumping stations driven by gasoline and diesel powered engines are located at the Mount Olivette and San Vicente reservoirs. Large swimming pools, such as the Olympic sized facility at Santa Monica City College, and others within the City may also be available as an emergency fire suppression water source. In addition, the 115,000 gallon capacity settlement basin in the vicinity of the Charnock well field east of the City, may supply a supplemental emergency source.

Fire and Building Code Enforcement: The Fire Department and the Department of Building and Safety presently administers the 1991 Uniform Fire Code (UFC) and Uniform Building Code (UBC); updated versions are adopted every three years. Relevant fire safety code standards and programs include:

- Section 8109.2, adopted by the City in December of 1989, requires that buildings or structures more than three stories or 30 feet in height, or more than 15,000 square feet shall be provided with an approved fully automatic sprinkler system. In addition, buildings or structures to be used primarily for public assembly of more than 5,000 square feet shall be provided with a fully automatic sprinkler system. Installation of sprinkler systems is also required in existing buildings where emergency access for fire apparatus or equipment is restricted. These requirements apply to existing as well as future developments.

- Division 3.02 of Section 8109.2 defines high-rise buildings as structures for human occupancy that measure more than 55 feet above the lowest level of Fire Department vehicle access, which is typically between five and six stories in height. High-rise building requirements are contained in Section 1807 of the Uniform Building Code, 1991 Edition, and Section 2-1807 of Title 24 of the California Administrative Code. These high-rise regulations include provisions for: 1) automatic fire extinguishing systems; 2) emergency stand by electrical power for fire warning systems; 3) emergency exit lighting and directional signs; and 4) emergency water pumps.

- New construction requirements are enforced for Class B roofing materials. As defined in the 1991 Uniform Building Code, Class B roofs are pressure treated, wood-shake shingles. They are not as resistant to fire as Class A roofs, which include ceramic and steel-covered wood tiles.

4.2 EARTHQUAKE INDUCED FIRE

An earthquake-induced fire and fire associated with Santa Ana winds pose the most extraordinary demands on fire suppression resources because of potential for multiple ignitions. Santa Monica is susceptible to both phenomena. The Oakland Hills Fire of October 1991 demonstrated the potential seriousness of multiple ignitions; a number of single and multi-family residential structures were simultaneously enflamed, and fueled by burning cinders fanned by winds. This mode of fire spread is termed "branding", a process that involves the wind transport of burning cinders outward a mile or more from the fire. Roofs are the most vulnerable portion of a building or structure to branding. Wood-shingle roofs, which is a particularly fire prone construction material, is prevalent in residential areas of the City.

- The City's Municipal Code, Division 9.00 of Section 8109.2, prohibits the use of untreated wood shingles or untreated wood shakes for new or replacement roofing.

The principal causes of earthquake-related fires include open flames, electrical malfunctions, gas leaks, and chemical spills. Commonly affected are unanchored gas heaters or gas-fired hot water heaters, appliances which tend to tip over during strong ground shaking. State law now requires new and replaced gas fired water heaters to be immobilized.

A study prepared by Scawthorn (1987) for the All-Industry Research Advisory Council used selected variables in a computer model to determine the post-earthquake fire risk for several jurisdictions in the Los Angeles Region (Table 4.2). Fire spread is modeled based on building construction and density, width of fire breaks, presence of flammable materials, wind conditions, water supply, fire department response times, and availability of fire fighting resources. This is a standardized model to measure loss estimates and damage rates. However, additional variables need to be considered with the scope of the Safety Element. The study reported the following conclusions for Santa Monica in the event of a magnitude 6.5 earthquake on the Newport-Inglewood fault:

- Post-earthquake fires occurring with no measurable winds would result in nine large fires, require seventeen engines, and result in an average response time of seven minutes, and a mutual aid response time of 76 minutes. Typical mutual aid response times computed by the model were between 70 and 90 minutes. A large fire is defined as a scenario in which the fire exceeds the fire suppression capability of one engine.

- Post-earthquake fires occurring during mild winds (10 mph) would cause nine large fires, result in response times of seven minutes, and mutual response times of 76 minutes, but would require twenty-eight engines.

TABLE 4.2

ESTIMATED IMPACT ON CITY OF SANTA MONICA FIRE RESPONSE AND SUPPRESSION RESOURCES FOLLOWING A POSTULATED MAGNITUDE 6.5 EARTHQUAKE ALONG THE NORTHERN NEWPORT-INGLEWOOD FAULT ZONE UNDER VARIABLE WIND CONDITIONS

JURISDICTIONAL CHARACTERISTICS	
FIRE PROTECTION	
4 Stations	8 Engines (5 staffed and 3 reserve)
BUILDING AREA	
84.3 million square feet	
INSURED VALUE ($ mil)	
2,993 Residential	3,331 Commercial

	WIND SPEED	
	0 mph	10 mph
NUMBER OF LARGE FIRES[*]	9	9
AVERAGE RESPONSE TIME (minutes)	7	7
MINIMUM ENGINE REQUIREMENTS	17	28
LOSS ($ mil)	169	236

[*] Large fires: suppression requires more than one engine

Source: Scawthorn, 1987, Fire Following Earthquake: Estimates of Conflagration Risk to Insured Property in Greater Los Angeles and San Francisco: AIG Industry Research Advisory Council, 83 p.

Note: Damaged water supply system due to ground failure, search and rescue, hazardous materials response, and medical treatment were not considered.

- Fire suppression capability of one City fire truck, as presently manned, is 1,500 gallons per minute (gpm), and engine capacities typically range from 400 to 500 gallons. The Insurance Service Office (ISO), which defines standards for fire flow, indicates that a single-engine could suppress a fire in a 388 sq. ft. wood-frame structure, 800 sq. ft. jointed masonry structure, a 1,230 sq. ft. noncombustible structure, or a 2,200 sq. ft. fire resistant structure. This value is increased by 25 to 50 percent if the structure is outfitted with fire sprinkler systems. According to data presented in Scawthorn (1987), the maximum capacity of an engine is 1,500 gpm.

The attached plates show a number of map elements which, by themselves, do not constitute a specific fire threat. It does however, lay out a framework to introduce some additional fire hazard issues in the City not addressed in the All-Industry Research Council Model:

- High-rise and mid-rise buildings are located in the western sector and the industrial and commercial corridors of the City. Existing high-rise and mid-rise buildings, and others planned for commercial zones, require special logistical support to fight fires, i.e., engines, special equipment and apparatus, and manpower, primarily because they exceed the height capacity of extension ladders of Fire Department trucks.

- Many areas of the City have narrow road widths and thus are less effective barriers to block fire spread. In addition, access of response vehicles to these regions may be restricted. Tunnels, overpasses and underpasses will also restrict clearance. Older commercial areas with narrow property setbacks and multifamily apartments are more susceptible to fire spread, especially where constructed of wood-frame and wood-shake shingle roofs.

- The Los Angeles County Transportation Commission, Summary Report of Los Angeles Transportation Facilities, prepared in June 1990, in response to extensive facility failures during the October 1989 Loma Prieta Earthquake, provides a risk prioritization of county-wide transportation facilities. Because of the use of single-column construction and the potential for liquefaction, interchanges of the Santa Monica Freeway (I-10) eastbound to northbound San Diego Freeway (I-405); the I-405 southbound to eastbound I-10; and the I-10 westbound to southbound I-405; ranked 1, 2, and 3, as the highest priority locations for retrofitting in the county-wide survey. Failure of these interchanges may further increase mutual response time during a disaster.

- The insurance industry computer model does not consider potential losses in water pressure due to breaks in the water distribution system. Cast-iron water pipelines are extensive in the City and are extremely vulnerable to damage. Water pipe lines once designed for single-family homes may not be able to support peak fire flow requirements for multi-family structures that are replacing them. Replacement utilizing plastic and concrete lines, in lieu of older cast iron systems is ongoing within the City. However, replacement is typically a result of development or redevelopment, which results in an increase of density and water demand. Ongoing water pipeline problems are generally located in older areas of the City. The liquefaction, surface rupture, and former clay pit areas shown on Plates 1 and 2 also delineate general areas where potential losses in water pressure might be concentrated due to pipeline breaks.

- Fire flow testing of the Santa Monica water hydrants was completed by ISO in 1992. Their findings indicates that all of the City fire hydrants exceeded the minimum 3,500-gallons per minute discharge rate, and also exceeded all needed higher flow requirements at specific hydrants. ISO continued the City's fire insurance classification at Public Protection Class 2, based on a rating formula involving alarm response, departmental procedures, and water supply.

- Primary gas transmission and distribution lines are shown on Plate 6. The California Division of Mines and Geology Newport-Inglewood Earthquake Scenario indicates that fire units should prepare for thousands of damaged and leaking mains, valves, and service connections, including broken pipelines along, and adjacent to, fault rupture (Toppozada et al., 1988). In some areas of Los Angeles County, the Southern California Gas Company (SoCal) has replaced distribution supply pipelines with resistant (flexible) plastic polyethylene pipe, and has an overall ability to isolate and shut-off sections of supply lines if breaks are serious.

- A Shell Oil Company 10 inch crude oil line traverses the City as shown on Plates 4 and 6. The pipeline enters the City from the north under 26th Street, bends to the west underneath Colorado Avenue, to the south beneath Cloverfield Boulevard, and finally to the west under Ocean Park Boulevard where it exits the City. The ten inch steel pipeline is buried approximately 4 feet deep. The route traverses densely populated residential and commercial areas of the City, and crosses the Santa Monica Freeway along the Cloverfield overpass. The oil line crosses areas of potential surface rupture, and localized spillage may occur as a result of primary ground surface rupture. In addition, areas of potential secondary ground rupture, such as liquefaction are crossed by the pipeline (Plate 1). According to the City of Santa Monica Fire Department (Coble, 1991, personal communication), the crude oil line is equipped with a safety valve located north of the Freeway crossing.

- Downed power lines may also ignite fires in the unlikely case they do not automatically deenergize.

CHAPTER 5: HAZARDOUS MATERIALS

Over the last few decades, our society has become increasingly dependent on the use of chemicals to improve our standard of living. Usage of such hazardous materials as gasoline to power our vehicles, chlorine to purify our drinking water supplies, and various pesticides and herbicides used around the home to control insects and weeds have become an integral part of our daily routine. Unfortunately, as the use of hazardous materials has grown over the years, scientists have discovered that exposure to assorted hazardous materials has adverse physical effects on mankind and the environment. Since the early 1970's, numerous Federal, State, and local legislations have been passed regarding the safe use, storage, manufacture, and handling of hazardous materials in order to decrease the risk of exposure of the general public to hazardous materials.

The State of California defines a hazardous material as a substance that is toxic, ignitable/flammable, reactive, and/or corrosive, and defines an extremely hazardous material as a substance that shows high acute or chronic toxicity, carcinogenicity, bioaccumulative properties, persistence in the environment, or is water reactive (California Code of Regulations, Title 22). The City of Santa Monica (City Ordinance No. 1554, 1990) has further defined hazardous materials as:

- Substances on the list prepared by the Director of the Department of Industrial Relations pursuant to Labor Code Section 6382;
- hazardous substances, as defined in Health and Safety Codes 25316 and 25532;
- any substance or material which is classified by the National Fire Protection Association as a flammable liquid, a class II combustible liquid, or a class III-A combustible liquid;
- any substance on the master list of hazardous substances prepared in accordance with Health and Safety Code 25281; or
- any substance required to be disclosed under Chapter 2 of Article V of the City Code relating to Toxic Chemical Disclosure.

This chapter will concentrate on the hazards associated with the existence of hazardous materials in, or adjacent to, the City of Santa Monica.

5.1 HAZARDOUS MATERIALS DISCLOSURE PROGRAM

Both the Federal Government and the State of California require all businesses that handle more than a specified amount of hazardous materials or extremely hazardous materials, termed a reporting quantity, to submit a business plan to its local administering agency. The City of Santa Monica's regulations are more stringent than both Federal and State requirements. The City of Santa Monica's Environmental Programs Division is the local administering agency. The City of Santa Monica has adopted a "zero reporting" requirement for businesses storing, using or manufacturing hazardous materials or extremely hazardous materials (Johnson, personal communication, 1991). City Ordinance Numbers 1400 (adopted January 27, 1987) and 1554 (adopted October 23, 1990) require that all businesses report to the local administering agency if they use, store, or manufacture any quantity of a hazardous material or extremely hazardous material. The submission or verification of business emergency plans, on a yearly basis, is required by the City if a business uses, stores, or manufactures an extremely hazardous material in any amount, or a hazardous material exceeding the reportable quantity of:

- 55 gallons or more of a liquid;
- 500 pounds or more of a solid; and/or
- 200 cubic feet or more of a gas at standard temperature and pressure.

The full business plan must include an inventory of the hazardous materials, and emergency response plans and procedures to be used in the event of a significant or threatened significant release of a hazardous material. The plan also requires immediate notification to all appropriate agencies and personnel of a release, identification of local emergency medical assistance appropriate for potential accident scenarios, contact information for all company emergency coordinators of the business, a listing and location of emergency equipment at the business, an evacuation plan, and a training program for business personnel.

Businesses that do not use store or manufacture hazardous materials above reportable quantities, but still use, store, or manufacture hazardous materials are required to submit an abbreviated business plan on a yearly basis with the local administering agency. The abbreviated business plan consists of emergency contact names and telephone numbers and a chemical inventory list (Coble, personal communication, 1991).

Business plans are designed to be of use to responding agencies, such as the fire department, during a release to allow for quick and accurate evaluation of each situation for appropriate response. Annually submitted business plans are currently reviewed by the Environmental Programs Division and by the Fire Department. The City has adopted Health and Safety Code 6.95 requirements into the Santa Monica Municipal Code 1400 to give the Environmental Programs Division and the Fire Department the authority to inspect businesses for compliance and accuracy of the submitted business plans. These inspections are performed on a yearly basis. A copy of the submitted business plans are maintained on the Command Vehicle which is dispatched to every hazardous material incident within the City (City Hazardous Material Communication Plan, 1990).

Currently over 600 business use, store, or manufacture hazardous materials or extremely hazardous materials in some amount. Plate 4 shows the location of the approximately 300 business that have filed full business plans with the City of Santa Monica indicating they use, store, or manufacture hazardous materials above reportable quantities, or extremely hazardous materials (Johnson, personal communication; Hazardous Materials Listing by Address, 1990).

Areas in the City showing high concentrations of reporting businesses include an area zoned for industrial manufacturing that runs through the center of the City, a commercial zone district located near the central eastern portion of the City, and the commercial zone districts along Pico, Broadway, Santa Monica, Wilshire, Montana, and Lincoln boulevards.

Nine businesses within the City currently use, store, or manufacture extremely hazardous materials, including ammonia, sulfuric acid, ethylene oxide, and sodium cyanide (Johnson, personal communication, 1991). In addition, the Fire Department has identified about 25 businesses that pose a significant risk to the community due to the volume or type of hazardous material used, stored, or manufactured. These business have been identified to provide for pre-emergency planning of local resources and evacuation routes. Pre-fire plans have been developed by the Fire Department for each of these businesses, and are maintained on each Fire Department apparatus in the Fire Department Communication Center (City Hazardous Materials Communication Plan, 1990). The City has also targeted businesses outside of the City limits that may potentially affect the City in the event of a hazardous material release. The Santa Monica Water Treatment Plant, located east of the City, stores and uses large quantities of chlorine. An industrial corridor located east of the City (south of Olympic Boulevard, between Olympic and Pico Boulevards) has also been targeted as a possible problem area (Coble, personal communication, 1991).

5.2 HAZARD ANALYSIS

The primary concern associated with a hazardous materials release is the short and/or long term effect to the public from exposure to the hazardous material, especially when a toxic gas is involved. The best way to reduce the liability for a hazardous material release is through stringent regulation governing the storage, use, manufacturing and handling of hazardous materials.

The City of Santa Monica Fire Department observes the 1991 version of the Uniform Fire Code for usage, storage, handling and transportation requirements for hazardous materials. Risk minimization criteria include secondary containment, segregation of chemicals to reduce reactivity during a release, sprinkler and alarm systems, monitoring, venting and automatic shutoff equipment, and treatment requirements for toxic gas releases.

Most of the City of Santa Monica is zoned for residential use, but in many instances industrial/manufacturing plants and commercial businesses that handle hazardous or extremely hazardous materials are located directly adjacent to residential areas, as shown in Plate 4. This close proximity of hazardous materials to residential tracts leaves the City open to the risk of a hazardous material incident affecting large sections of the population.

5.2.1 Hazards Associated with Natural Disasters

Plate 4 shows that a large number of business that handle hazardous or extremely hazardous materials are concentrated in a strip zoned for manufacturing or commercial use that runs through the center of the City. This strip, which is about 4,000 feet wide, is generally located between Wilshire Boulevard and the Santa Monica Freeway. When Plate 4 is overlain with plates presented in other chapters of the Safety Element, this area shows a marked potential for hazardous materials incidences associated with natural disasters as discussed below:

- Figures 1.3 through 1.12 show that this area could experience Modified Mercalli intensities in the VIII range as a result of an earthquake on the Newport-Inglewood fault. Higher seismic intensities could be generated by earthquakes on the Santa Monica or Malibu Coast faults. The strong ground motions expected to be generated by an earthquake on any of the above three faults could cause major structural damage to many of the facilities using hazardous materials located in this area. Under a worst case scenario, several hazardous materials releases could occur simultaneously.

- Plate 1 shows that the Santa Monica fault crosses the eastern portion of this area, through the manufacturing zone district. Surface rupture of this fault could result in damage to a few of the facilities where hazardous substances are used or stored.

- Plate 1 shows that the eastern portion of the area zoned for manufacturing is susceptible to liquefaction during an earthquake generating strong ground motions in this part of the City. Hazardous material containers not properly secured and fastened could easily be punctured and/or tipped over. Improperly segregated chemicals could react forming a toxic gas cloud. Under a worst-case scenario, it is possible that several hazardous materials releases could occur simultaneously.

- Plate 2 shows that portions of the manufacturing and commercial districts in the northeastern section of the City are located on abandoned clay pits and/or landfills. If the foundations of some of these structures housing hazardous substances are seated on artificial fill that is not properly compacted, differential settlement of these fills as a result of an earthquake could cause severe structural distress to the structures. This in turn could result in the release of hazardous substances from damaged containers.

- Plate 3 shows the eastern portion of the area zoned for manufacturing is located within the potential inundation path for the Stone Canyon Reservoir.

5.2.2 Crude Oil Pipeline

A ten-inch diameter crude oil pipeline owned by Shell Oil Company traverses the eastern portion of the City, from north towards south. This pipeline is buried about 3 to 4 feet, paralleling 26th Street, Broadway, Cloverfield and 23rd Street. The pipeline is about 40 years old, and has ruptured in three locations outside of the City (City Hazardous Materials Communication Plan, 1990). The pipeline passes through areas susceptible to liquefaction. This pipeline could rupture in the event of a large earthquake on the Newport-Inglewood fault, or on other nearby faults, resulting in strong ground shaking or liquefaction of the soils. The pipe could by primary rupture of the Santa Monica fault.

5.2.3 Abandoned Clay Pits and Landfills

The clay pits and abandoned landfills located within the manufactured and commercial zone districts in the northeastern section of the City may also pose an environmental hazard if hazardous waste buried in these pits and landfills is uncovered. An open clay pit near the vicinity of Colorado Place was apparently backfilled with some municipal waste from the City of Beverly Hills (Johnson, personal communication, 1991). During a geology and soils investigation for a proposed parking structure, Crandall (1978) encountered debris and explosive gases in borings to depths of up to 39 feet. Crandall's study evaluated approximately two city blocks north of Colorado, between Cloverfield Boulevard and 26th Street. The geotechnical boring logs report that up to 80 percent of the debris encountered in the borings consisted of asphalt, wood, brick, concrete and other inert fill materials. Measurements of a potentially explosive gas mixture, probably methane, was encountered in one boring. Uncertified fills to depths of approximately 15 feet were noted by Crandall (1989b) in investigations for the proposed "Arboretum" south of Colorado, between 20th Street and Cloverfield Boulevard.

5.3 HAZARDOUS MATERIALS INCIDENT RESPONSE

There are nine million (CAS Service, France) different chemicals available today, each with its own unique physical characteristics; what might be an acceptable mitigation practice for one chemical could be totally inadequate for another. Therefore, it is essential that agencies responding to a hazardous material release have as much available information regarding the type of chemical released, the amount released, and its physical properties to effectively and quickly evaluate and contain the release. The annually submitted business plans can be an excellent resource for this type of information. Another source of information can be knowledgeable facility employees present onsite.

The Santa Monica Fire Department responded to 367 hazardous materials incidents during fiscal year 1992-93. Of these 367 incidents, 199 were gasoline, diesel, and oil spills; 4 were solids; 35

were flammable and non-flammable gas releases; 4 were poison/infectious waste; 24 were "other", including paint, antifreeze, and asbestos; and 93 were false alarms (no material found or material found was not hazardous, i.e. water). Representatives of the Environmental Programs Division responded to an additional 111 incidents (City Annual Hazardous Materials Incident Report, 1991). Most of the incidents handled by the Environmental Programs Division include small quantities of household type hazardous wastes, such as waste oil, paint, thinner, pesticides, etc. The Environmental Programs Division immediately contacts the Fire Department if an incident is beyond their responding capabilities (Coble, personal communication, 1991).

The City of Santa Monica has entered into a mutual aid agreement with the County and the City of Los Angeles. The Los Angeles County Department of Health Services mobile laboratory is available to the City to aid in identification of unknown substances. In addition, the chemical database CHEMTREC, which includes data on toxic effects, physical properties of the substance, etc., is used to provide information to the Fire Department on the suspected chemicals involved in an incident. The City of Santa Monica currently owns two ENMET-90 combustible gas and toxic detectors to assist in defining concentrations of airborne contaminants. If a hazardous materials release is beyond the capabilities of the Santa Monica Fire Department, the City or County of Los Angeles Hazardous Materials Units are requested to mitigate the release. Releases occurring on the Santa Monica Freeway within the City are handled by the California Highway Patrol with assistance from the City of Santa Monica (Coble, personal communication, 1991).

5.3.1 Incident Command System

The City of Santa Monica Fire Department is in the process of implementing a Comprehensive Hazardous Materials Response Team. This team will perform the following funcations:

- Classification and identification of unknown chemicals.
- Mitigation, control, and containment of spilled or leaking chemicals.
- Decontamination of victims.

Currently 16 members of the Fire Department and 2 from the Environmental Programs Division (EPD) are trained to the Haz-Mat Technical/Specialist level. The Fire Department acts as "First Responder" with assistance provided by the EPD.

The City of Santa Monica has adopted the Incident Command System (ICS) to manage hazardous materials incidents. The City's Hazardous Material Incident Contingency Plan identifies three levels of hazardous materials response:

- Level I: Abandoned container or spilled 55-gallons or less of a suspected petroleum product or products with low toxic hazards, or a release to the storm drain of a small volume of petroleum product. These releases are within the capabilities of, and are therefore handled by, the Santa Monica Fire Department. Low toxic hazards generally include petroleum wastes including waste oil, hydraulic fluid, crude oil, etc.

- Level II: Abandoned container or spilled substance greater than 55-gallons of suspected petroleum product or products with low toxic hazards but still within the capability of the City Fire Department's resources. Releases at this level require notification and/or assistance from the State Office of Emergency Services, Los Angeles County Waste Control (Health HazMat), and other local fire department hazardous materials response teams.

- Level III: Unidentified products, any amount of products with a high toxic hazard, or when the volume of the release exceeds the City's capabilities. This level of response also includes releases to the storm drain of substances other than petroleum products. The primary response unit is the City's Fire Department. Direct requests are made to the City or the County of Los Angeles Hazardous Materials Units for assistance. The nearest mutual aid hazardous materials unit is approximately 10 minutes from the City limits under normal driving conditions.

5.3.2 Evacuation

The Incident Commander (either the CHP for a release on the Santa Monica Freeway, the Santa Monica Fire Department, or the City of Los Angeles or the County of Los Angeles Hazardous Materials Unit) is responsible for ordering an evacuation. The decision to evacuate is made based on the type of contaminant, the amount released, and the possible health effects to the population. The Santa Monica Police Department assists with the evacuation. Public notification is currently made via the Emergency Broadcast System and KAJZ Radio (FM 103.1). Established evacuation shelters include designated facilities shown on Plate 7.

The optimum order to protect the public from a chemical release/toxic cloud is "sheltering in place", unless the released material is a flammable gas. Sheltering in place consists of advising the affected population to stay indoors, close all windows, and shut off all ventilation systems.

5.3.3 Fire Department Resources and Responsibilities

The Fire Department has four fire stations, eight engine companies, two rescue units, and five paramedic units available for emergency response (four of the engines double as paramedic units). The Command Vehicle is maintained out of Station #1 (Fire Department Headquarters). Communications during a hazardous material incident is via the Fire Department's tactical radio frequency, with backup communications provided via the cellular telephone and facsimile machine maintained in the Command Vehicle. As the primary response unit, the Fire Department is responsible for:

- Identifying released substances and determining the hazard potential and specific mitigation alternatives;
- taking action to contain and/or prevent the spread of the material;
- determining the extent of the effected area for perimeter control, and reevaluating the perimeters as additional information is received and analyzed;
- determining the existing or potential rescue requirements;
- assessing the need for, and ordering, evacuation of effected area(s);
- securing the services of an appropriate cleanup agency; and
- collection of fees for equipment and resources expended at haz-mat incident. (Also known as Cost Recovery)

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AERIAL PHOTOGRAPHS

Date	Flight No.	Photograph Nos.	Scale	Collection
3-1927	C-30	B:1-2; C:1-3; D:1-4; E:1-3	1" ≈ 3,000'	Fairchild
8-1927	C-113	16-20, 25-30, 38-42, 55-59	1" ≈ 3,000'	Fairchild
1-1928	C-164	1-10	1" ≈ 1,500'	Fairchild
6-25-28	C-235	A:1-12; B:1-15; C:1-12; D:1-16; E:1-13; F:1-13; G:1-12	1" ≈ 3,000'	Fairchild
1928	C-300	J;235-237, 255-265, 282-288 (Partial Negs)	1" ≈ 3,000'	Fairchild
9-18-31	C-1670	1-7	1" ≈ 1,500'	Fairchild
10-2-33	C-2773	1-10	1" ≈ 1,500'	Fairchild
3-10-34	C-3060	2-9	1" ≈ 1,500'	Fairchild
2-22-35	C-3358	1-2	1" ≈ 1,500'	Fairchild
2-28-35	C-3390	1-15 (Partial Negs)	1" ≈ 1,500'	Fairchild
2-20-37	C-4353	1-2	1" ≈ 1,500'	Fairchild
2-20-37	C-4354	1-7	1" ≈ 1,500'	Fairchild
12-13-87	C-4915	2-10	1" ≈ 640'	Fairchild
4-1-38	C-5084	3-8	1" ≈ 3,000'	Fairchild
1-5-40	C-6233	1-4	1" ≈ 3,000'	Fairchild
5-1940	C-6330	38-46, 50-55	1" ≈ 3,000'	Fairchild
10-6-40	C-6630	2-7, 13-17	1" ≈ 3,000'	Fairchild

AERIAL PHOTOGRAPHS

Date	Flight No.	Photograph Nos.	Scale	Collection
7-3-41*	C-7220	3-11	1" ≈ 700'	Fairchild
7-18-41	C-7255	5-11, 15-22, 28-35	1" ≈ 3,000'	Fairchild
4-22-46	C-10288	1-2, 12-13	1" ≈ 3,000'	Fairchild
11-15-46	C-10890	1:21-24, 40-47, 51-60,62-68,88-90; 3:1-6,15-24,34-43, 50-54	1" ≈ 3,000'	Fairchild
1-1-47	C-11023	19-20, 25-27; 3:4-7, 41-44	1" ≈ 3,000'	Fairchild
6-47	C-11351	9:18-22, 33-37, 47-50 (Partial Negs)	1" ≈ 3,000'	Fairchild
8-22-47	C-11703	3:2-5, 18-19, 23-24; 4:34-36; 5:1-3, 18-19 (Partial Negs)	1" ≈ 3,000'	Fairchild
5-17-48	C-12594	T:3-6, 25-27	1" ≈ 3,000'	Fairchild
6-2-49	C-13775	J:5-9 (Partial Negs)	1" ≈ 3,000'	Fairchild
8-14-49	C-14165	1:9-21, 32-40	1" ≈ 500'	Fairchild
10-21-49*	C-14180	2:11-16,27-29; 3:26-27,53,57-66; 4:1,5:1-8 (Partial Negs)	1" ≈ 500'	Fairchild
10-1950	C-15695	2:17-18, 20, 49-50	1" ≈ 3,000'	Fairchild
	C-15695X	1:41-45		
8-15-52	C-17979	18:23-25 (Partial Negs)	1" ≈ 3,000'	Fairchild
7-14-53	C-19375	3:31-32	1" ≈ 3,000'	Fairchild

AERIAL PHOTOGRAPHS

Date	Flight No.	Photograph Nos.	Scale	Collection
12-18-54	C-21250	95-99, 108-112	1" ≈ 2,000'	Fairchild
2-6-56	C-22407	1:1-14, 20-33, 56-85 (Partial Negs)	1" ≈ 500'	Fairchild
4-5-56	C-22478	1:2-4	1" ≈ 3,000'	Fairchild
	C-22926	3:147-151, 158-162, 177-179 (Partial Negs)		
11-20-62	C-24385	1:1-5 (Partial Negs)	1" ≈ 3,000'	Fairchild
	X-16	1-6		

* Denotes flights with very good coverage of former clay pit areas.

GLOSSARY

Abatement - The reduction or elimination of a hazardous condition, including but not limited to strengthening, occupancy restrictions, or demolition.

Active Fault - A fault that shows evidence of, or is suspected of having experienced surface displacement within the last 11,000 years. An active fault is considered to have the highest potential for future surface rupture.

Accelerograph - An instrument used to record very large earthquakes.

Aftershocks - Earthquakes that follow a main larger earthquake, most commonly smaller than the main shock.

Alluvium - Surficial sediments of poorly consolidated, gravels, sands, silts, and clays deposited by flowing water.

BAREPP - Bay Area Regional Earthquake Preparedness Project.

Bedrock - Designates hard rock that is in its natural intact position and underlies soil or other unconsolidated surficial material.

Catastrophic Earthquake - A great earthquake, generally near Magnitude 8.0 or greater, capable of widespread tremendous damage in the epicentral area accompanied by localized severe damage hundreds of miles from earthquake source.

Coseismic Rupture - Rupture occurring during an earthquake.

Critical Facilities - The definition of critical facilities in the glossary of the Safety Element takes precedent. The following are categories of critical facilities referenced in this report:

a. Any lifeline system facility under County jurisdiction whose operations are essential at times of emergencies, such as energy transmission systems, major utility lines, evacuation and disaster routes, and warehouses storing heavy rescue and debris cleanup equipment;

b. essential facilities that are needed in times of emergencies, such as medical facilities, fire and police stations, emergency operation centers, and communication centers;

c. high-risk facilities that, if severely damaged, could cause catastrophic casualties or disasters far beyond the facility itself, such as nuclear power plants, dams and flood control infrastructure, freeway-to-freeway interchanges and bridges, and industrial plants which manufacture or store explosives, toxic materials, or petroleum products;

d. high occupancy facilities having potential for catastrophic fatalities and crowd control problems such as high-rise buildings, large assembly public and private facilities and large multifamily residential complexes;

e. dependent care facilities that house populations with special evacuation considerations, such as educational facilities for preschool, public and private schools, rehabilitation centers, prisons, and major social care facilities, including group care homes and elderly care facilities; and

f. economic facilities whose continued operation is paramount to avoiding severe economic impact, such as banking, vital record keeping, archiving activities, airport and port facilities, and large industrial/commercial complexes.

Dekameters (Dam^3) - Unit of dam storage capacity where 1 Dam^3 is equal to .8 acre-feet. An acre-foot is the volume of an acre of area that is one foot in thickness.

Deterministic - Synonymous with designating a maximum credible event for the seismic design of a structure.

Differential Settlement - Nonuniform settlement; the uneven lowering of different parts of an engineering structure, often resulting in damage to the structure. Sometimes included with liquefaction as ground failure phenomenon.

Dynamic Analyses - A complex earthquake-resistant engineering design technique (UBC - used for critical facilities) capable of modeling the entire frequency spectra, or composition, of ground motion. The method is used to evaluate the stability of a site or structure by considering the motion from any source on mass, such as that dynamic motion produced by machinery or a seismic event.

Earthquake - Vibratory motion propagating within the earth or along its surface caused by the abrupt release of strain from elastically deformed rock by displacement along a fault.

EERI - Earthquake Engineering Research Institute.

Emergency Operations Center - A room or building equipped and staffed to monitor and direct the response to an emergency situation.

Engineering Geologist - A geologist who is certified by the State as qualified to apply geologic data, principles, and interpretation to naturally-occurring earth materials so that geologic factors affecting planning, design, construction, and maintenance of civil engineering works are properly recognized and used. An engineering geologist is particularly needed to conduct investigations, often with geotechnical engineers, of sites with potential ground failure hazards.

ESS - Earthquake Safety Systems.

Fault - A fracture (rupture) or a zone of fractures along which there has been displacement of adjacent earth material.

Fault Mechanism - A model of the sense and orientation of the generating fault displacement.

Fault Slip Rate - The average long-term movement of a fault as determined from geologic evidence (measured in cm/year).

FEMA - Federal Emergency Management Agency.

Frequency Composition - The range of frequencies as measured at a site, including high frequency earthquake ground motion (greater than 1 Hz) and lower frequency energy (less than 1 Hz).

Geotechnical Engineer - A licensed Civil Engineer who is also certified by the State as qualified for the investigation and engineering evaluation of earth materials and their interaction with earth retention systems, structural foundations, and other civil engineering works.

Ground Failure - Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.

Ground Rupture - Displacement of the earth's surface as a result of fault movement associated with an earthquake.

High Occupancy - High occupancy can be defined as exceeding 100, 200, and 500 person capacity, depending on importance factors of the facility, i.e., dependent care and other building uses.

Intensity - A subjective numerical measure of the effects of an earthquake at a particular place. Intensity depends on the earthquake magnitude, distance from the epicenter, and on the local geology, and the subjective and/or empirical observations of damage in particular cultural setting, i.e., construction standards.

Isoseismal Area - An area composed of points of equal earthquake intensity on the earth's surface.

Lateral Force - The force of the horizontal side-to-side motion on the earth surface as measured on a particular mass, either a building or structure.

Lateral Spread - Shallow angle slope failure caused by liquefaction of a subsurface layer; very large displacement.

Levee - An artificial embankment of earth fill, built along the bank of a water course or an arm of the sea and designed to protect land from inundation.

Lifeline System - Linear conduits or corridors for the delivery of services or movement of people and information (e.g., pipelines, telephones, freeways, railroads).

Liquefaction - Changing of soils (unconsolidated alluvium) from a solid state to weaker state unable to support structures; where the material behaves similar to a liquid as a consequence of earthquake shaking.

Magnitude - A measure of the size of an earthquake, as determined by measurements from seismographic records.

Major Earthquake - Capable of widespread, heavy damage up to 50+ miles from epicenter; generally near Magnitude Range 6.5 to 7.0 or greater, but can be less, depending on rupture mechanism, depth of earthquake, and location relative to urban center, etc.

Moderate Earthquake - Capable of causing considerable to severe damage, generally in the range of Magnitude 5.0 to 6.0 (Modified Mercalli Intensity < VI), but highly dependent on rupture mechanism, depth of earthquake, and location relative to urban center, etc.

Near-Field Earthquake - Used to describe a local earthquake within approximately a few fault zone widths of fault which is characterized by high frequency waveforms that are destructive to above-ground utilities and short-period structures (less than 2- or 3-stories high).

Nonductile - Refers to concrete construction using columns and beams with insufficient steel reinforcing, making a structure brittle and prone to collapse during earthquakes.

Nonstructural Hazard - Fallen or broken interior or exterior building components such as stains, piping, windows, wall partitions, electrical conduits, lights, brick veneer, equipment, etc.

Parapet - The portion of any wall which extends above the roof line, or a wall that serves as a guard at the edge of a balcony or roof.

Piling - Used to pin a structure to stable bedrock below using long piles emplaced through an unstable zone of potential ground failure; commonly utilized for landslide and liquefaction mitigation.

Peak Acceleration - The greatest amplitude of acceleration measured across a record left on an accelerogram.

Potentially Active Fault - A fault showing evidence of movement within the last 2 million years, but which has not been proven to have moved or not within the last 11,000 years; capable of generating damaging earthquakes.

Project - A development application involving zone changes, variances, conditional use permits, tentative parcel maps, tentative tract maps, and plan amendments.

Power Intertie - Terminal facilities in a lifeline network system, such as water and sewage pumping stations, electrical power substations, and power generating facilities.

Poison Distribution - A probability distribution that characterizes discrete events occurring independently of one another in time.

Probabilistic Assessment - Seismic risk assessment that accounts for how often and how strongly the ground will shake from surrounding seismic sources. The designation of a maximum probable earthquake is probabilistic.

Pseudostatic - A simplified engineering analysis of the stability of a site or structure that translates earthquake ground motion into a static force in performing stability calculations.

Reinforced Masonry - Masonry construction with steel reinforcement.

Resonance - Amplification of ground motion frequencies within bands matching the natural frequency of a structure and often causing partial or complete structural collapse; effects may demonstrate minor damage to single-story residential structures while adjacent 3- or 4-story buildings may collapse because of corresponding frequencies, or vice-versa.

Response Spectra - The range of potentially damaging frequencies of a given earthquake applied to a specific site and for a particular building or structure.

Seismic Capacity - The measure of resistance of a structure to strong earthquake shaking, or seismic loading as commonly used when applying lateral forces to a structure.

Seismogenic - Capable of producing earthquake activity.

Seismology - The study of earthquakes.

Soft-Story Construction - A structure that has at least one story, often the ground level, with significantly less rigidity or strength than other floors in the structure during seismic loading, e.g., apartment dwellings with garages on the lower floor, etc. A soft-story is considered to have less than 70% of the stiffness of the story above, while a weak-story possesses less than 80% of the strength of the story above.

SSC - Seismic Safety Commission.

Site Amplification - An increase in the seismic signal amplitude within some frequency resulting from propagation through crust, topography, earth materials at the site, bedrock and alluvium contact, etc.

Standard Cone Penetrometer - A engineering borehole measurement, which among other applications, is able to translate penetration resistance (as gauged from a narrow cylindrical instrument of standard weight dropped from a standard height) of unconsolidated earth materials into a measure of liquefaction susceptibility.

Storage Capacity - Is measured in acre-feet and decameters, including dead storage.

Strike-Slip Fault - A fault with a vertical to subvertical fault surface in three dimensions that displays evidence of horizontal and opposite displacement.

Structural Engineer - A licensed Civil Engineer certified by the State as qualified to design and supervise the construction of engineered structures.

Tectonics - A mechanical model relating the movement of several rigid crustal plates over an underlying plastic layer. The juncture of adjacent plates can be one of convergence, spreading, or sliding along a transform tectonic plate boundary.

Tilt-up Wall - A poured concrete-and-steel-reinforced wall raised or lifted into place and tied to other walls, and to the roof and floor.

Veneer - A covering layer of material for walls, which is attached to the wall, but not bounded adequately so as to act with it during earthquake shaking.

Water Table - The upper surface of ground water which saturates pores and fractures in rock or surficial earth materials.

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